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The Effect of Music and Light-Color as a Machine Empathic Response on Stress in Occupational Health

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***Abstract*— In a world where technological advancements are progressing at a vertiginous pace, social networks, online games, virtual worlds, streaming services, and remote work are part of everyday life. This is the case for the work environment, with the use of technological tools and home offices. In contrast, harmful aspects have been amplified, such as stress that affects occupational health. Lately, considerable interest has been gained in the affective domain in improving the occupational situation using empathic responses. In this work, we study the effect of machine empathic responses such as blue light, relaxing music, and the combination of light and music on people performing stressful tasks in an occupational environment. Thirty five participants tested different stimuli, eleven tested the music condition, twelve the light effect, and another twelve the combination of light and music. The monitoring of the heart rate variability along with psychological measures show that empathic responses can help reduce humans stress levels.**

Index Terms – **Artificial Agents, Empathic Machine, Occupational Stress, stressor, Light-color and Music, Calm Technology, Affective Computing, Human-Machine Interactions.**

I. INTRODUCTION

Stress is one of the so-called modern disorders and in some cases *modern diseases* [1], [2]. A problem that is gaining ground in our society day by day, caused by diverse factors to which humans are exposed in daily life. It may involve simple aspects such as environmental discomfort caused by changes in temperature or external noise levels, up to critical situations that involve traumas rooted in personality or situations that generate an impact at the psychophysiological level [3].

Therefore, it is increasingly relevant for people to find alternatives for reducing the negative effects caused by stress factors in their everyday activities, and it is better when these alternatives merge and adapt to the environment and activities performed [4], especially in the occupational environment. Technology plays an important role through affective computing, a branch of computer science that has steadily evolved to achieve advances through a multidisciplinary approach, exploring how technology can inform the understanding of human affect and interact with such technology in a natural, empathic, and affective way [5]. In other words, it positions the human beyond being a mere user of technological devices and tools to be the core of the entire process, adapting the technology to the physical and/or mental particularities of the individual to offer capabilities tailored to them.

Affective computing is based on the application of perception-action mechanisms, which finds its origins in psychology [6], defining humans as individuals who are constantly evaluating their environment through the stimulation of their senses and generate reactions to such stimuli after processing, analyzing and pondering all that information. Here, affective computing seeks to recreate such behavior in machines [7]. Through constant monitoring of the affective and emotional state of an individual (perception), the machine is able to offer through predefined techniques or artificial intelligence alternatives emphatically positive and adjusted to what the person needs (action), an aspect that frames this research.

In this paper, we address the human state enhancement through machine empathic actions by using light and music as empathic responses. Section II exposes the related work and background of this study. Then in Section III is presented the experiment conception, design, and architecture. The results and analysis in Section IV and finishing with conclusions and future work in Section V.

II. RELATED WORK

Some works related to the purpose of this research have been identified in the literature, which will be addressed in this section. An overview of related works of empathic responses using light, color, and / or music to control or reduce stress, verifying relevant aspects, such as the generation of stress or used stressors and the measures of indicators involved in the process, followed by an exploration of how this has been implemented in the occupational environment.

A. Light/Color Based

Stimulation of the visual system in humans plays an important role in affective computation according to Sokolova et al. [8] as it directly affects an individual's emotional state by altering the luminance characteristics of the environment, for example, color and light are factors that modify the emotional state of an individual in a nonverbal way. Kaya et al.[9] expose the relationship between emotions and colors from the perspective of humans. They associated colors such

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as green and blue with emotions of relaxation, calm, and comfort. Or red with anger, excitement, passion.

Based on similar concepts, Yu et al. [10], proposed *De-light*, a system based on ambient light for inducing relaxation state and stress control in person. Based on the calm technology concept [11]. The experiment implemented monitoring of heart rate variability (HRV), where light with *warm* tones was used to increase the level of arousal and thus increase performance. While the *cool* tones were used to decrease arousal inducing states of relaxation and calmness

On the other hand, Daher et al. [12] with the aim of improving the empathic interaction between Human-Computers, they used blue light for stress reduction. For this purpose, 17 participants were evaluated and subjected to mental arithmetic task stressors under the influence of blue-colored light compared to its absence. Physiological stress levels derived from heart rate (HR), electrodermal activity (EDA), and psychological stress levels using self-perception tools such as the Perceived Stress Scale.

B. Music Based

Music is used as a therapy or a widely accepted relaxation technique in the field of health and medicine [13]. The sedative and stimulating music effects studied by Jiang et al. [14] considered user preferences on stress reduction taking into account the effects of a stressful task. The results suggest that the effects of sedative or stimulating music depend on the user's preference, which is important in reducing stress or eliciting an emotion related to calmness or relaxation.

The project of Yu et al. [15] assesses stress levels in real time, while presenting a biofeedback response that reflects the user's state of anxiety and stress. This project, called *UnWind*, aims to provide a biofeedback interface that merges natural sounds with sedative music to promote relaxation. The results found by using UnWind conclude that the user is able to improve HRV by regulating breathing, thus reducing physiological levels of arousal and psychological anxiety.

On the other hand, Chen et al. [16] considered the temporal factors involved in listening to music in stress reduction, that is, how the duration of listening to music or the time relative to the occurrence of a stressor influences the psychophysiological levels of stress. The participant listens to the preferred music at different stages of the process, depending on the evaluation group. The results of this study showed that listening to music before a stressful event significantly reduces stress levels than after the occurrence of it.

C. Music and Light/Color Based

After Delight [10], Yu et al. considered the use of sounds in *RESonance*. This project was described as "*lightweight, room-scale audio-visual biofeedback for immersive relaxation training*" [17]. Both light-color and sound were used as a biofeedback response to the state of anxiety and stress levels of the user. A direct relationship is established between stress levels and the saturation of blue-green light. As well as between stress level and the volume and density of sound generated. The goal of this direct relationship is to inform the user of their stress level and to induce a state of relaxation through breathing exercises.

D. Occupational Environment Based

In the workplace, Stefani et al. [18], proposes *SmartHeliosity* which evaluates human emotions to provide the best choice of colored light to improve the emotional state of workers. Using emotion recognition techniques in facial gestures, SmartHeliosity is able to offer in response a color combination predefined by a database related to the specific emotion, e.g. blue and green tones for calm and relaxation emotions. Overall, as a result, color-based light stimuli generate subjective changes in the emotions of the person experiencing them.

Ren et al. [19] proposed *LightSit*, which considers physical inactivity and increased stress in the workplace by sensors placed on the user's chair that track body posture and periods of inactivity with continuous HRV monitoring for the detection of stress levels. With the use of light integrated to the support of the monitor, it displays information without distracting the user, facilitating relaxation exercises during micropauses. The results show that LightSit has the potential to improve user well-being in the workplace.

The related work mentioned above involves multiple aspects relevant to this study; most of them are biofeedback or training systems to induce a relaxing state when the user does not perform any other task. Although the purpose of this study is to observe and measure how stress levels are affected when a person is exposed to the effects of colored light and/or music stimuli during the performance of stressful tasks, considering as context any one that involves a person in front of a computer, i.e. the office environment.

III. EXPERIMENT

A. Experiment Design

The experiment is intended to collect and analyze data concerning the behavior of humans when they are exposed to occupational stress situations, such as those involving mental effort, considering the exposure to colored light and/or music stimuli and no stimuli at all. For this purpose, the following hypothesis is proposed, which will be validated or rejected.

Null Hypothesis: There is no difference in user physiological or psychological indicators, when participants perform mental arithmetic tasks under three different stimulus.

1) Physiological and psychological indicators: For physiological indicators, the measurements obtained by the PPG sensor, that is, IBI and HR, it is possible to obtain HRV, which is based on the measurement of a consecutive series of duration of the cardiac cycle, which means that the lower the HRV the higher the level of stress or arousal, and vice versa, by Acharya et al. [20]. This behavior can be observed in the time domain by calculating the Baevsky's Stress Index (SI), Root Mean Square of Successive Differences (RMSSD), and Standard Deviation of RR intervals (SDRR) [21].

For the psychological indicators, especially self-perceived stress, we used the Perceived Stress Scale (PSS) questionnaire [22], a reduced version of PSS used in [23] and the Self-Assessment Manikin (SAM) questionnaire [24] during the experiment.

2) Architecture: A detailed architecture is proposed that considers different components and their relationship with the user. There are four main modules that will be detailed in the following and are visible by rounded boxes in Figure 1, and the relationships between them.

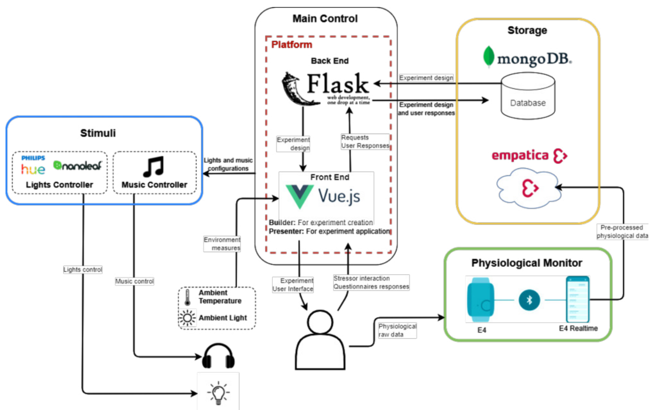

Fig. 1. Architecture for the experiment to observe the effects of music and/or light on stress in occupational health.

The **Main Control**[1] provides a direct interface with the user, which also establishes communication with the other modules, such as sending collected data to the Storage module or controlling light and sound in real time through instructions sent to the Stimuli module. This module consists of two important components:

- The Backend, developed in Python and Flask, offers a RESTful API interface for the control and interaction of the system. It is responsible for the logic implementation of the experiment.
- The Frontend developed in Javascript and Vue.js offers a web interface to the users.

It is important to note that this module implements two modes: the Builder mode for the creation and management of experiments, and the Presenter mode for execution of the experiment created.

The **Stimuli** module, the blue box on the left side of the architecture, is in charge of controlling of the devices for the generation of stimuli (lights and headphones). This module receives as input the instructions predetermined by the main control, and as output, the module controls the devices that execute these instructions.

The **Storage** module, represented by the yellow block, aims to store information concerning the design and protocol of the experiment in Builder mode, and to return the protocols and configurations of the experiments created, storing user data, such as session, responses, performance and settings in Presenter mode. This module was implemented using nonrelational database mongoDB Atlas. In addition, this module involves the empatica cloud as a cloud storage site for user physiological measurements.

The module **Physiological Monitor** responsible for monitoring and collecting physiological data from the user is located on the bottom right side in green. It consists mainly of the Empatica E4 device, which is a wristband that monitors different indicators. This module receives as input the information obtained from the device, processes it, and sends it to the storage module, previously described.

Finally, a small module is considered to monitor the brightness of ambient light and the ambient temperature.

B. Experiment Delivery

Details concerning the deployment and delivery of the experiment such as the scenario and protocol of implementation are discussed below.

1) Scenario: Two important premises have been considered since the beginning of this study: the context of an office, based on occupational health, and the theory behind the concept of calm technology [11], which allows the participant to focus their attention on the performed task.

Figure 2 depicts the proposed scenario, where the location of the devices are shown in relation to the participant. For example, in Figure 2.a is a perspective from behind the participant where the center of the action is on the computer screen. In the top-down perspective of Figure 2.b, it is easier to see the distribution of the elements on the desk. Likewise, the position of the empatica E4 wristband on the participant's arm and the headphones is also visible.

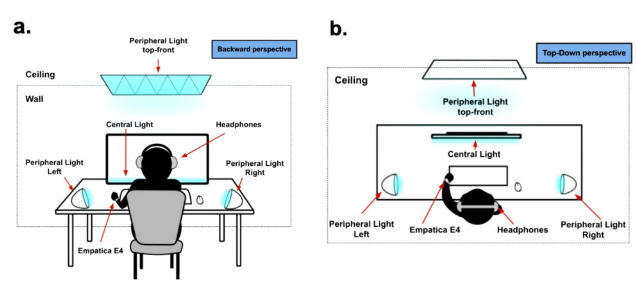

Fig. 2. Scenario for experiment implementation. **a.** Backward perspective, **b.** Top-Down perspective.

2) Experiment Protocol: The workflow is made up of 9 steps that cover the entire process, as shown in Figure 3.

- Step 1: Initial preparation and consent signature.
- Step 2: Preliminary information, rules, instructions for sensor setup, and calibration of devices.
- Step 3: A simple breathing exercise to normalize the participant's physiological indicators.
- Step 4: The first questionnaire has PSS, SAM, reduced version of PSS, and some customized questions.
- Steps 5 and 8: Stressor tasks are based on mental task arithmetic operations and its instructions.
- Steps 6 and 9: The intermediate and final questionnaires, respectively. Both contain the reduced version of the

[1] https://github.com/andres112/StressEvaluator

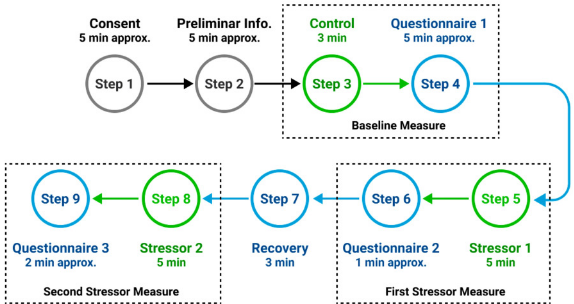

Fig. 3. Experiment workflow protocol.

PSS and the SAM. In addition, in Step 9, additional questions are asked related to the experiment.

- Step 7: Transitional step between stressful tasks, to restore physiological indicators just after the first stressor.

IV. RESULTS AND ANALYSIS

A total of 35 participants (12 women and 23 men) between 17 and 63 years old participated in the experiment exposed previously, of which 12 participants performed the experiment using both stimuli and 11 using only music. Furthermore, the results of 12 participants evaluated by Daher et al. [12] are considered because the experimentation parameters, the evaluation protocol, the measured indicators and the setting are similar to the one implemented here, but using the blue light condition.

A. Physiological Results

Below are the results and analysis of the HRV obtained from Inter Beat Interval (IBI) and Hearth Rate (HR) monitoring, collected by the empatica E4 wristband.

1) Heart Rate Variability - HRV: Three indicators of HRV are evaluated, according to the stress index (SI), the mean square standard deviation (RMSSD), and the standard deviation between the RR intervals (SDRR). One-way Anova is implemented as an evaluation method. The equality of variance by means of the Levene's test and the normalized distribution of the data are validated.

Table I summarizes the results of the analyzes for each of the groups evaluated. It is important to clarify that the results are reported in the form $F(df_B, df_W) = [F_{value}]$ refers to F-value, where df_B degree of freedom between groups, df_W degree of freedom within the group, followed by the $p = p_{value}$ and the effect size η^2, in order to validate the degree of statistical significance between the groups. As a reference, for values of $\eta^2 > 0.37$ there is a large effect size.

As it can be observed, there is a statistical significance for the 3 indicators, where light has a better effect on stress than the other two groups that involve a musical component. This can be seen in the Post Hoc test in Table II for each of the indicators, light presents a lower SI than the other groups, as well as a higher RMSSD and SDRR, which is indicating a lower stress level. Therefore, it is possible to reject the null hypothesis because for both SI, RMSSD, and SDRR, the p-values are less than 0.05.

SI	RMSSD	SDRR
$F(_{2,17.049}) = 24.890$ $p < 0.001$ $\eta^2 = 0.458$	$F(_{2,31}) = 12.58$ $p < 0.001$ $\eta^2 = 0.448$	$F(_{2,32}) = 13.192$ $p < 0.001$ $\eta^2 = 0.452$

TABLE I

STATISTICAL ANALYSIS FOR HYPOTHESIS, COMPARING BOTH VS. MUSIC VS. LIGHT FOR HRV.

Stimuli	MUSIC	BOTH
LIGHT	$p - value_{SI} = 0.001$ $p - value_{RMSSD} = 0.002$ $p - value_{SDRR} < 0.001$	$p - value_{SI} < 0.001$ $p - value_{RMSSD} < 0.001$ $p - value_{SDRR} < 0.001$
BOTH	$p - value_{SI} = 0.759$ $p - value_{RMSSD} = 0.805$ $p - value_{SDRR} = 0.863$	

TABLE II

POST HOC TEST FOR BOTH VS MUSIC VS LIGHT IN BETWEEN GROUPS FOR HRV.

In addition to the analysis presented above (between group analysis), we also performed the analysis for comparing the use of stimuli and without the use of them at all. It was considered for 33 of the 35 participants (within group analysis) according to the experimental methodology used. The results are visualized in table III, where it is obtained for RMSSD and SDRR a statistical significance in which the use of stimuli shows a better effect on stress compared to when not. For SI, no clear statistical significance is obtained, although a better effect on stress reduction is observed when stimuli are used. It is important to clarify that the values expressed in the form $t(df) = [t_{value}]$ refers to Paired-sample t test and $W = [W_{value}]$ to Wilcoxon's signed rank test when the data do not follow a normal distribution, followed by the $p = [p_{value}]$.

SI	RMSSD	SDRR
$t(32) = -0.838$ $p = 0.408$	$t(32) = 2.198$ $p = 0.035$	$W = 365$ $p = 0.06;_{With \neq Without}$ $p = 0.03;_{With < Without}$

TABLE III

STATISTICAL ANALYSIS FOR THE WITHIN-GROUP TEST, COMPARING WITH VS. WITHOUT FOR HRV.

B. Psychological Results

From psychological point of view, the perception that each participant has of themselves is evaluated at the moment of assessing the level of stress. Although this aspect has a high level of subjectivity, due to factors that may affect the emotional and affective state of the participant, it is important to analyze these results.

1) Perceived Stress Scale - PSS: This tool is used to obtain the participants' self-perception of stress prior to the execution of the experiment. Therefore, the measures obtained here are a reflection of the initial state of the participants, as shown in Figure 4, the most of the participants are at a moderate stress level, just before starting the experiment.

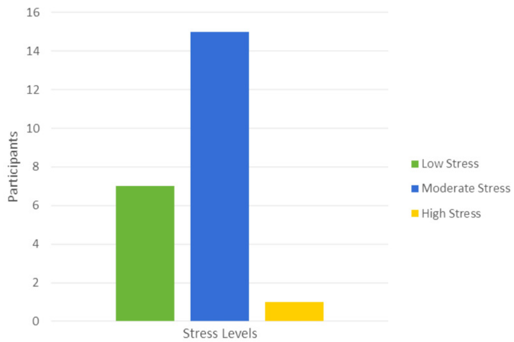

Fig. 4. Initial self perceived stress of participants according to PSS.

The emotional state and the level of stress prior to participation influenced the performance of the participant, such as the case of the participant who presented a high level of stress, who notably showed to be stressed throughout the experiment.

2) Perceived Stress Scale - Reduced Version: This indicator shows the behavior of self-perception of participants throughout the three main stages of the experiment, baseline or control, WITH stimulus effect and WITHOUT stimulus effect.

Stimuli	Stress	Tension	Concentration
BOTH	$\overline{X}_{Base} = 4.33$ $\overline{X}_{With} = 5$ $\overline{X}_{Without} = 5.5$	$\overline{X}_{Base} = 4.25$ $\overline{X}_{With} = 5.08$ $\overline{X}_{Without} = 5.5$	$\overline{X}_{Base} = 6.5$ $\overline{X}_{With} = 6.91$ $\overline{X}_{Without} = 7.08$
MUSIC	$\overline{X}_{Base} = 4.63$ $\overline{X}_{With} = 6.09$ $\overline{X}_{Without} = 6.54$	$\overline{X}_{Base} = 3.72$ $\overline{X}_{With} = 5.63$ $\overline{X}_{Without} = 6.64$	$\overline{X}_{Base} = 7.18$ $\overline{X}_{With} = 7.63$ $\overline{X}_{Without} = 6.91$
LIGHT	$\overline{X}_{Base} = 4.33$ $\overline{X}_{With} = 6.27$ $\overline{X}_{Without} = 6.61$	$\overline{X}_{Base} = 4.05$ $\overline{X}_{With} = 6.66$ $\overline{X}_{Without} = 6.55$	$\overline{X}_{Base} = 6.22$ $\overline{X}_{With} = 6.11$ $\overline{X}_{Without} = 5.16$

TABLE IV

SUMMARY OF THE MEAN VALUES AND STANDARD DEVIATIONS OF THE REDUCED VERSION OF PSS FOR BASELINE, WITH AND WITHOUT.

Table IV quantitatively shows the difference between the mean values for each of the conditions of the independent variables evaluated.

- The average values of the baseline that correspond to the prior stage of control are lower than the average values of the stages involving stress, which is clear evidence that, according to the participants, a change was indeed produced that increased their stress and tension levels.
- The use of stimuli, blue light, relaxing music, or both (WITH) has a slightly better effect (lower values) on the level of stress perceived by the participants than when they are not used (WITHOUT).
- For perceived tension, it is also lower when music is involved as a stimulus, that is, for BOTH and MUSIC groups. However, for LIGHT, the behavior is opposite, although not significant.
- Concentration, however, was perceived by the participants as higher when the stimuli are applied individually, i.e., when relaxing music or blue light is used in a stressful task. The opposite behavior was observed for both stimuli (BOTH), with a difference of $\overline{X}_{With-Without}$= -0.166, a lower value compared to the other groups.

C. Other Results

Table V shows the variation between WITHOUT and WITH, where **+** indicates an increase in WITH with respect to WITHOUT and **-** a reduction. Here it can be seen that for BOTH and MUSIC there is an increment of hits and a reduction of errors under the effect of the stimuli, whereas for the LIGHT group, the opposite was the case.

Stimuli	Error$_{Without-With}$%	Hits$_{Without-With}$%
BOTH	- 0.7%	+ 4.7%
MUSIC	- 6.34%	+ 10.58%
LIGHT	+ 9.53%	- 5.6%

TABLE V

SUMMARY OF VARIATION OF THE PERFORMANCE OF PARTICIPANTS FOR BOTH, MUSIC, AND LIGHT.

Meanwhile, Figure 5 shows the feedback of the participants according to which stimulus reduced their stress level (left) and which increased the most their stress level (right). It can be seen that 65% of the participants reported a reduction of stress with the stimuli, while 43% of the total participants perceived that the musical stimulus positively affected their stress level. On the other side, 22% for only music, 17% for the combination of music and light and 4% for only light perceived the increment of their stress level, respectively, but the remaining 57% of the total participants reported that the use of stimuli did not increase their stress level.

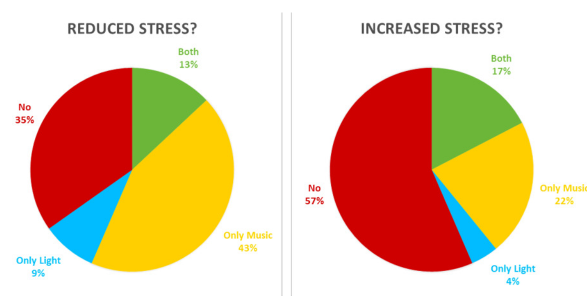

Fig. 5. Participants' responses to Do you think the use of colored light and/or music REDUCES your stress level?(left) and Do you think the use of colored light and/or music INCREASES your stress level?(right).

Physiologically HRV was a relevant indicator in this study to reject the null hypothesis, and this result was achieved with blue light, demonstrating the relevance of this stimulus compared to music. Although for the psychological component, it was not possible to obtain statistical significance to reject the hypothesis, even so, there were results that favor the use of stimuli to reduce the stress perceived by the participants, where the use of the musical stimulus, particularly, exhibited a greater benefit against stress.

V. Discussion and Conclusions

Statistical significance for HRV was obtained between the three groups for the reduction of occupational stress among the evaluated participants, where blue light was the stimulus with the lowest stress index and the highest values of RMSSD and SDRR compared to the groups involving music. Therefore, it can be inferred in this aspect that the blue light used in the experimental process contributed to the reduction of stress in the participants subjected to stressful tasks in a better way than music and the combination of music and light.

In the particular case of the combination of music and light condition, the participants possibly felt involuntarily affected by the combination of the two stimuli at that time, since the other groups, where the stimuli were used individually (only music and only light), the HRV showed a positive contribution to stress reduction. Maybe the combination of these stimuli, considering temporal factors, i.e., first music, then light, could generate better results.

Taking into account the participants' self-perception, even though there was no statistical significance in the analysis of the results of the PSS and SAM, these showed relevant information indicating that the use of stimuli positively affects the reduction of stress, especially for the combination of music and light, and only music conditions which also increased the concentration on the task performed.

Furthermore, it was also observed that not only stress is affected by these stimuli, but the performance in the execution of mathematical operations showed a slight improvement in participants when stimuli such as relaxing music were present, with this and the fact that participants reported that their concentration level on average increased; relaxing music generates an effect of concentration and improved performance, as long as it does not distract their attention, as specified by the concept of calm technology.

The context in which the individual is situated plays a fundamental role in stress levels; an example of this was the initial stress level of people prior to their participation in the experiment, which influenced their performance. Such as the case of a participant who reported a high initial PSS score (see Figure 4 - yellow bar), who was quite stressed at the time of performing the arithmetic operations.

Even blue light showed better performance over music and the combination of music and light; there was not a significant difference with respect to the use or lack of stimuli for stress reduction, therefore, to obtain statistical significance, it would be necessary to increase the number of participants in the experimental process.

Throughout this study, stress and its effects on humans were considered as the core to which all concepts addressed were related, such as empathy, emotions, or occupational health and how this negatively affects individuals who suffer from it and their environment, when it is not treated correctly and in a proper and opportune way. That is why affective computing in conjunction with various areas of psychology, health, science, and others, seek to control and reduce their levels to mitigate their harmful effects.

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