

Modelling The Combined Effect of Indoor Environmental Condition on Neurobehavioral Trends of Individuals Through Electrocardiogram

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Abstract

The current study is aimed at evaluating the combined effects of indoor noise, light and temperature on human neurophysiological responses. This study included 34 individuals who were exposed to varying temperatures (16 degrees Celsius, 22 degrees Celsius, and 31 degrees Celsius), light (150 lumens per meter square, 250 lumens per meter square, and 500 lumens per meter square), and noise levels (20 decibels, 50 decibels, and 90 decibels) in 27 sessions in a simulated indoor setting. 67% accuracy was achieved for KNN model. Accuracy can be increased with increasing amount of data of participants. Furthermore, the effects of temperature on heart rate were more substantial than the effects of noise. Overall, noise for longer duration has a stronger negative impact on working memory of male, whereas temperature has a more severe influence on neurophysiological response of female. On other hand, male performed well in high temperature than female. To the best of our knowledge, this is the first study to examine the relationship between ECG and IEQ. The study culminated with directions for further studies.

Keywords

Electrocardiogram, Machine learning, Noise, Temperature, Light.

1. Introduction

Due to current pandemic situation, 90% people usually spend most of their time in enclosed locations such as their homes and offices [1]. Indoor Environmental Quality (IEQ) mainly include lighting, temperature and noise level, which could have a significant impact on occupants' neurobehavioral, health, and job performance. The term neurobehavioral refers to the impact of the brain on emotion, behavior, and learning to do tasks of varying degrees of complexity. Human behavior is influenced by the interior environment, which has a major impact on human performance [2]. However, the effects of a certain IEQ factor on human neurobehavioral are highly upon job of individuals. As a result, it is critical to understand the influence of indoor environment on mental and physical state of human body.

Previous research has shown that excellent IEQ enhances occupant happiness and productivity in general [3, 4]. However, there has been contradictory data on the impact of individual IEQ variables on various performance and productivity measures. In addition, a review of current research in this subject indicates that the majority of studies have focused on the individual impacts of specific environmental variables on human perception, such as the thermal, auditory, visual, and air quality aspects [5, 6]. Few researchers have looked at the connections between various indoor environmental variables and human perception [7-10].

As reported by [11], combined effect of noise and temperature using heart rate, and skin temperature were analyzed only on 35 male participants which make their results gender biased. In [12], the connection between light environment on mood and alertness was studied using illuminance range is 100-1000 lx. In [13], a microcontroller-based Arduino was used to measure and process the ECG signals. The primary contribution of this research is the transmission of an ECG to a particular smart mobile phone for monitoring by a doctor, but irrespective of indoor environment. Similarly, some authors used noise, light or temperature but combined effect of IEQ with respect to age, gender and profession

is not available in literature. There is insufficient data to draw valid conclusions. Therefore, it's critical to conduct a comprehensive study of human comfort utilizing objective data.

In addition, predicting the ECG is normal or not, using the combined effect of IEQ factors on different gender, age group and profession is not available in literature using Machine Learning (ML). Currently, no fully automated machine learning based system exist which use noise, age and gender information as input and predict their effect on human neurobehavioral pattern and ECG. The focus of this study is to provide automated system which predict human ECG abnormality and neurobehavioral pattern considering their gender, age and profession. The current work is an attempt to comprehend the relationship in depth.

Mainly there are three objectives of this research study. Firstly, to determine the correlation between noise, light and temperature and their combine effect on human using cognitive task performance as well as with ECG. Secondly, to investigate correlation of combined effect of noise, light, temperature depending on human age, gender and profession. Thirdly, to implement various Machine Learning algorithms such as K-Nearest Neighbors (KNN), Support Vector Machine (SVM), Logistic Regression (LR) to predict the combined effect of IEQ on human

2. Experimental Setup and Data collection

Data collection is very time consuming and challenging task. In literature, no one captured data of ECG signals along with indoor quality measure. The experiment was carried out in a medical laboratory at COMSATS University Islamabad for 27 consecutive days. Area of room where experiments were conducted was 300 square feet. ECG300GA Electrocardiograph 12 lead machine was used to capture ECG signals of participants. A total of 34 participants were pre-selected, with 17 males and 17 females. The participants ranged in age from 18 to 69 years old. All of the participants worked for free. Participants were either students, teachers, or university administrators. All subjects were obliged to wear the same outfit (a shirt and pants) and take part in all the experiments. The university's ethics committee authorized all protocols, and each participant gave written informed consent prior to the experiment.

Apart from participants, 1 medical nurse and 2 cardiologists helped to capture and analyzed ECG. All personal participant's information was not included in the data. Our focus was to capture ECG signals with different indoor measures like noise, temperature and light. Due to pandemic situation the study only considered three possible values for each indoor measure like high, medium and low. Therefore, $3*3*3= 27$ days. We performed these experiments 27 days with different combination at each day as shown in **Table 1**.

Firstly, for light we used 150, 250 and 500 (lux, lumens/m²). We used "Lux Light Meter Illuminance App" was used to measure light. Secondly, for noise we recorded a single audio of 5 minutes contained different sounds of mobile ringing, people conversation, walking sound and passenger car sound. We played this audio with 20, 50 and 90 dB for silent, moderate and loud noise respectively. Lastly, for temperature we keep room temperature at 16°C, 22°C and 31°C respectively for low, moderate and high temperature. Temperature was measured using Digital Thermometer Hygrometer (DTH).

2.1 ECG

ECG is one of the most common methods for detecting heart related issues. ECG is a non-invasive diagnostic tool for assessing the electrical and muscular activities of the heart on a regular basis. **Fig. 1** depict the procedure to we used capture 12-lead ECG. **Fig. 1 (a)** depict full apparatus used for collecting ECG signals. ECG monitor along with limb electrode, bulb/chest electrode, glue, wires for connections. Proper electrode placement is critical for correctly measuring the heart's electrical activity. There are 12 leads determined using 10 electrodes in a 12-lead ECG. **Fig. 1 (b)** and **Fig. 1 (c)** depict how we attach limb electrode on left and right arms and legs. Black, red, yellow, green electrodes were attached to right leg, right arm, left arm and left leg respectively. This color order must be same whenever ECG was performed. Six bulb electrodes were attached to the chest using glue as shown in **Fig. 1 (d)**. **Fig. 1 (f)** show final printed ECG on paper.

Table 1: Experimental day details with noise, temperature, and light Val

Day	Noise dB	Light lumens/m ²	Temperature °C	Day	Noise dB	Light lumens/m ²	Temperature °C
1	90	500	31	14	50	250	22
2	90	500	22	15	50	250	16
3	90	500	16	16	50	150	31
4	90	250	31	17	50	150	22
5	90	250	22	18	50	150	16
6	90	250	16	19	20	500	31
7	90	150	31	20	20	500	22
8	90	150	22	21	20	500	16
9	90	150	16	22	20	250	31
10	50	500	31	23	20	250	22
11	50	500	22	24	20	250	16
12	50	500	16	25	20	150	31
13	50	250	31	26	20	150	22
				27	20	150	16

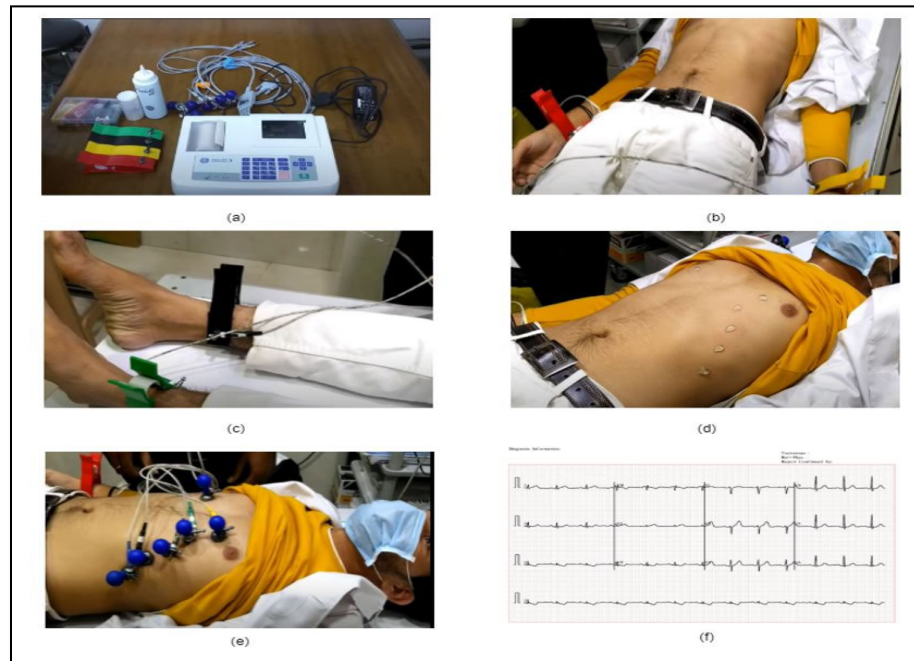


Fig. 1: 12-lead ECG data collection procedure

2.2 Working memory

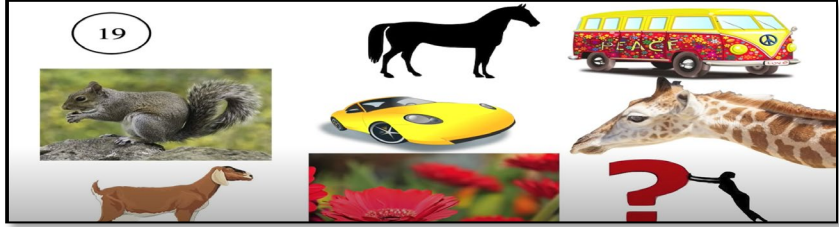
Once ECG done, we asked every participant to give a “Computerized Cognitive Assessments” test. Which help us to evaluate their cognitive ability under different indoor conditions. In this task, we ask participant to first watch a video of 1-3 minutes. Each day we play different videos, and at the end of video we asked participants to give answer what they see in video. Digit span where participant have to write order in which digits shown form 0-9, list name of object they see, or ask colors of objects, or ask about order of images shown and so on as shown in **Table 2**. After this activity we give them points out of 10 based upon their correct answers. This activity helped us to access their memory conditions and response time.

2.3 Data pre-processing

This is very interesting step of our methodology. As we captured ECG in the form of images contain 12 lead information. Along with ECG we gathered information through questionnaire which contain in words and sentences. We used machine learning to convert ECG paper records into a 1- D signal. All personal information was removed from input image of our ECG data. Next step was to divide input image into 13 leads for additional information. Further processing applied on each individual leads (1-13) by eliminating gridlines, changing to grayscale, applying Gaussian filtering, and performed thresh holding to convert to binary image. Using the contour approach, the modified image was traced to extract only the signals and the values are scaled using the Min-Max Scalar.

The normalized output is stored as a 2D signal in Comma Separated Value (CSV) format. The X-axis refers to the high and low points, whereas the y axis corresponds to the curve/shape. We concentrated on the low/high points in our study, the X-axis will be stored separately as a normalized scaled 1D signal in a CSV file. In questionnaire we have numeric data which contain memory score of each participant. Professional information was replaced with 0, 1 and 2 for admin staff, teachers and students respectively. For gender we give 1 value for female and 0 for male. Finally, we add these values along with noise, temperature and light values for respective participants in our csv file.

Table 2: Questionnaire Sample

Participant ID	Marks Obtained: _____ Experiment Day: _____	Questions
Response time:	Early finish test: _____ Full time: _____ How many questions remained: _____	<ol style="list-style-type: none"> 1. How many pictures were there? 2. Which picture was on the top right corner of the screen? 3. What was the lady pushing? 4. What was the color of the car? 5. Can you name the six living things you saw? 6. What was the color of flower?
Input Image in video		

3. Experiments and Results

Supervised models perform best when huge amount of data is provided for training and testing. Ratio for training and testing was 80:20. 80% of data was used for training of model and remaining 20% was used to evaluate the model. Multiple classifiers are applied, including k-nearest neighbors (KNN), Logistic Regression (LR), Support Vector

Machine (SVM), and gradient boosting decision tree XGBoost model. Iteration for each model was finished based on acceptable accuracy, precision, recall, f1-score, and support criteria.

Table 3 show ML model performance using all features as well as eliminating 1 feature at a time. Overall KNN gives best performance. KNN's core concept is to look about your neighborhood, suppose the test data point is comparable to them, and then deduce the result. We find best n=4 neighbors for our data. Logistic regression does not perform well due to multi collinearity. As in our data set, we have features variables which are highly related to each other. For example, age and profession are highly correlated to each other. As age increase profession change. Similarly, high temperature causes abnormal heartbeat. Therefore, LR model does not perform well in our dataset. Collinearity and outliers tamper the accuracy of LR model.

Table 3: ML models accuracy comparison with different features elimination.

Features elimination	ML models							
	KNN (n=4)		SVM		LR		XGBoost	
	Training Accuracy	Testing Accuracy	Training Accuracy	Testing Accuracy	Training Accuracy	Testing Accuracy	Training Accuracy	Testing Accuracy
'Gender'	0.66	0.53	0.59	0.53	0.83	0.52	0.88	0.52
'profession'	0.67	0.55	0.59	0.53	0.83	0.51	0.88	0.55
'Age'	0.67	0.5	0.78	0.48	0.82	0.52	0.84	0.50
No elimination	0.67	0.58	0.59	0.54	0.83	0.52	0.88	0.55

When the number of dimensions exceeds the number of samples, SVM method works well. Non-linear decision boundaries may be modelled using SVMs, and there are several kernels to pick from. They're also resistant to overfitting, especially in high-dimensional spaces, don't require distribution, and aren't affected by multi-collinearity. SVMs, on the other hand, use a lot of memory, are more difficult to adjust due to the necessity of choosing the proper kernel, and don't scale well to bigger datasets. The following are the XGBoost model's flaws: When dealing with data that include a lot of categories, it's possible to over fit. Are unstable and have a lot of volatility, have a hard time expressing additive structure, and have poor predictive ability. **Table 4** show ML models comparison in term of accuracy, precision, recall and F1-score.

Table 4: ALL models result comparisons

Model	Training Accuracy	Testing Accuracy	Precision	Recall	F1- score
KNN	0.67	0.58	0.58	0.58	0.54
SVM	0.59	0.54	0.43	0.54	0.40
LR	0.83	0.52	0.52	0.52	0.52
XGBoost	0.88	0.55	0.55	0.55	0.55

Comparison of female and male performance under different room conditions with normal ECG shown in **Fig.2**. Female performed well under high noise and low performance under high temperature. Male performed very well under high temperature but performance decrease in noisy environment. Both male and female performed well under 250 luminance value. Indoor condition does not affect memory of participants, due to mainly majority of participants are young and energetic and 5-10 min indoor environment doesn't affect their memory. If we increase time for simulated environment this may affect memory as well.

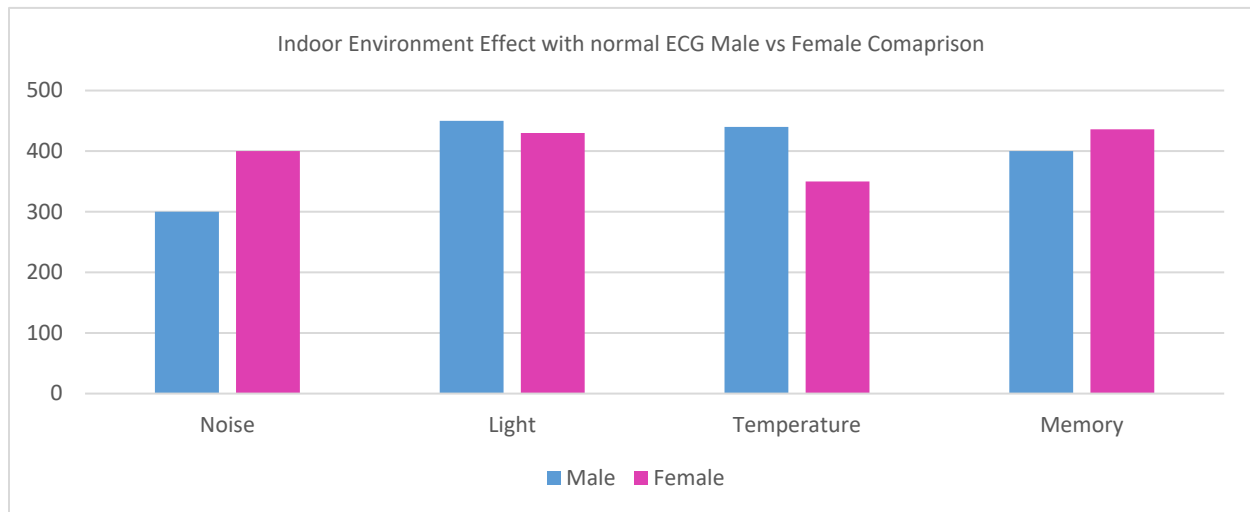


Fig. 2: Indoor Environment Effect on male vs female

4. Conclusion

To the best of our knowledge, this is the first study to examine the relationship between ECG and IEQ. Human brain and heart behave differently under different environmental conditions. Our focus is to make a correlation between ECG, light, noise and temperature. First, we convert automatically all ECG images into numerical columns and then we apply machine learning algorithms to make final prediction.

The emphasis in this study is on detecting and extracting patterns from Electrocardiogram picture reports. The requirement for time-consuming human intervention to understand the report can be avoided by digitizing ECG recordings. The automation of diagnosis and analysis may be accomplished more quickly with digitalization. We achieved 67% accuracy for KNN model. Accuracy can be increased with increasing amount of data of participants. ECG images were transformed into 1D data and then we add more information about memory condition, age, gender, profession after experiments of noise, temperature and light.

From results noise mainly effect male as compared to female. Females show positive attitude when they were exposure to high noise. On other hand, male show outstanding performance when they exposed to high temperature. Light has natural effect. If we increased light intensity this effect headache but overall, on 200-500 Luminance is best for office work environment. Noise cannot be removed in any office completely so people are used to it. Temperature can be managed and mainly this effect our breathing and hence effect our ECG and brain working.

Working memory and neurophysiological responses were disrupted in the investigated experiment settings as temperature and noise increased. The results showed that noise had a substantial influence on working memory when compared to air temperature. The combined impacts of noise, light and temperature were greater than the influence of each factor alone. The rise in light intensity had no effect on reaction accuracy in the context of high noise levels. However, in the presence of loud noise, the increase in temperature exacerbated the mean value of neurophysiological reactions.

5. Discussion and future work

Due to pandemic situation, we capture data for less people. In future, this work can be done on a greater number of people, which increase our ML model accuracy. This system can be further implemented in hospitals to monitor patient ECG and we can make better room for patient regarding his/her age, gender, profession etc. In addition, this model can be implemented in schools, classrooms and offices to make better indoor environment and hence this will be good for brain and heart working.

Automatically digitizing ECG record to 1D data and then further categorized this into normal or abnormal heartbeat is helpful for doctors. This will save their time and help them to make accurate and efficient decision about patients. This will reduce workload of doctors by manually inspecting ECG graphs. In future, this work can be used in homes to make them better place, save energy and comfortable environment for living. Once we will gather more data, unsupervised model can be used for model training and testing. This will reduce burden of manually annotation process of ECG images into normal or abnormal. More profession can be added in future to have versatile data about participants. As profession mainly effect human stress level. In every job stress level is different and based on job type and age, environmental factors effect differently on individuals under the same roof.

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