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Έξυπνα Μεταβαλλόμενα Περιβάλλοντα Εργασίας: Ο ρόλος τους στο γνωστικό έργο
Smart transformable architecture for work environments: Their role in cognitive tasks

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Contents

Abstract

Several researches have shown that visual perception and level of attention are strongly affected by lighting conditions of the environment. The combined effects of color temperature, light intensity and ambient light parameters seem to play an important role in cognitive tasks. In the current thesis we investigated these hypotheses in the context of smart room environments (SMR). SMRs are able to adapt themselves in order to enhance the level of attention and the visual stimulation of people working in them. These transformable interior spaces are not only capable of changing the lighting conditions but also the spatial characteristics of the environment in real time.

For this purpose we carried out four experiments. During the first two experiments we used a conference auditorium with three variations of ambient luminance conditions; one with high, one with low and one with continuously changing luminance. We used the oculus rift, a virtual reality headset, where the participants were able to interact with the conference auditorium. We examined the effect of ambient luminance in the room on sustained attention in two different tasks; in Experiment 1 we used a target detection task and in Experiment 2 a memory task. In the Experiment 3 we examined the effect of lighting color in attention with two different lighting conditions; red and blue in the same conference auditorium, the same task and with the same equipment as Experiment 2. In the last experiment (Experiment 4) we tried to verify the results of the Experiment 2 in real environment, not a simulated one.

Results showed that extreme lighting conditions might affect both attention and memory. These results though, were not confirmed in the real environment.

The current research could help in the understanding and the implementation of smart learning and/or working environments.

Keywords: Smart Transformable Environments, Sustained Attention, Lighting conditions, Wellbeing.

1. Introduction

Illumination in workplace and educational environments is of great importance as it has been shown to affect both productivity and wellbeing of students and employees.

Wellbeing is strongly correlated with health, including general physical and mental health, social participation, diet, substance use, etc. The term is also defined as quality of life, quality of relationships, individual's values and achievements. Wellbeing reportedly has two dimensions· the first is *satisfaction*; in other words cognitive assessments and second is the *positive feelings* or the felling of happiness. Cognitive assessments connected with a person's thoughts and feelings of happiness are defined as a state of good mood (Bourke & Geldens 2007).

Productivity is a term that is strongly related to performance. According to Sinha (2001), performance is a combination of willing and openness that a person has in order to do his/ her job. When the levels of these factors are high, employee's productivity increases which also leads to better performance. According to Howell and Hall- Merenda (1999) employee's social interactions in the workplace play a major role in performance. There are alternative definitions for performance in a work environment given by several researchers but in order to better understand the term it might be useful to explain how we can measure performance.

The measurement of performance is different among people. For example to measure students performance, the teacher watch their grades or see if they completed the task they had to. Employees similar to students have to complete a task in order to achieve organization’s goal and that is the measurement of their performance (Stup, 2003).

The factors that have been determined as important in workplaces are: “job aid, supervisor support or relationship, opportunity to get promoted, performance feedback, goal setting, workplace incentives, mentoring, coaching and also the physical work environment” (Naharuddin & Sadegi 2013). In the same work, they choose to study the physical work environment and more specifically the ergonomic arrangement. The main factors that affect employees are light, noise, ventilation, temperature, floor configuration, office layout and furniture layout. Working in a proper work environment has as result less stress during office hours, better performance and help employees from not getting nerve injury (Naharuddin & Sadegi 2013).

Boyce et al (2006) analyzed the linked mechanisms between light conditions and work environment. Changing the lighting conditions, immediately affects employee’s visual comfort, visual capability and the way they perceive the environment. Depending on the work’s requirements, these three aspects seem to interact with each other. For example, a change in lighting conditions can change the way the employee perceives the work place, may cause visual discomfort which in turn can cause difficulties in completing tasks. These conditions directly affect the mood and in the long term, mood affects wellbeing. Continuing the chain, wellbeing has an impact on motivation which is strongly related with performance. They also conclude that the employees control over the lighting conditions from morning to evening has a beneficial effect to them (Boyce et al, 2006).

The first investigations into the impact of changes in work environment upon employees productivity and wellbeing, were carried out in the 1920 and early 1930s in Hawthorn industry by Professor Mayo and his team. Hawthorn industry was a western electric industry near Chicago in which employees productivity according to the industries manager was far from the ideal, although there were many benefits such as health care and pension system. At the beginning, the research hypothesis was that better lighting conditions will decrease employees fatigue and feelings of tediousness and as a result, their productivity would increase. The experimental group was working under high lighting conditions and the control group under the same lighting conditions they were working before. This procedure lasted two years and no statistically significant results were found between the two groups. After this, Mayo separated six women from the assembly line in a separate room and put them under supervision. At the same time, he changed their lighting conditions and after any change, their supervisor explained them what they wanted to achieve from every change. These women become indeed more productive, returned earlier from their lunch break and finished their work earlier.

These results were quite confusing. The lighting conditions indeed affected productivity, fatigue and feelings of monotony. On the other hand, the researcher, attributed the success of the second experiment in the idea of these six women that they were important in the assembling line and their employer was interested in improving their working conditions. So the conclusion drawn was that employee’s productivity rises when they feel their employer cares about them. Therefore, cognitive factors outweigh changes in environmental factors in a work place. (Hart, 1943, Harris, 1994).

After this study many researchers started to explore the relationship between productivity and workplace conditions. The majority of them confirm that lighting conditions play an important role in productivity; however others suggest that there are no statistically significant results by which the productivity associated with lighting conditions. It is also important to clarify, which lighting conditions are more beneficial according to the task that the employees have to achieve.

Boray, Gifford & Rosenblood (1989) reported no differences in performance in simple verbal and quantitative tasks between warm white (3000K), cool white (5000K), and full-spectrum fluorescent spectra lighting (7500K). They also speculated that some differences might exist but were quite small and undertaken.

Veitch, Gifford & Hine (1991), compared the reading performance and the self-reported arousal in two different lighting conditions, full spectrum lighting and cool white fluorescent lamps. The first group was separated in three different subcategories. In the first, the experimenter told to the subjects that this type of lighting will help them improve their performance, in the second that the lighting in this room will affect negatively their performance and the third was neutral. As for the second group, those who exposed to cool white fluorescent lamps, the experimenter informed them neutral about the lighting condition. There were no statistically significant differences between the two main conditions. As for the data analysis between the subcategories of the first group, results showed that the subjects who were informed positively or negatively about the lighting conditions, had better performance in the task and reported being more aroused.

There is also a linking between arousal and performance in the “Arousal theory”. “Arousal theory predicts that performance is best at moderate levels of arousal but deteriorates when arousal is too low or too high. The nature of the task, such as the speed and accuracy of proof-reading, may put different demands on arousal" (Hockey as it mentioned in Küller & Laike, 1998).

According to Bellia, Bisegna & Spada (2011),environmental lighting correlates positively with human health and performance. Circadian rhythms are disrupted by inappropriate lighting conditions and as a result the health and performance in everyday life may be disrupted as well. It is known from Zee, Attarian & Videnovic (2013) that disturbance of circadian rhythms, may pose a problem in sleep cycle, body temperature, feeding, hormone secretion, glucose homeostasis and regulation of cell cycle. Moreover, circadian rhythm disorders are associated with cognitive impairment and mood disturbances (Zee et al 2013).

However, it is important to clarify which are the most appropriate lighting conditions for work environments. Viola, James & Schlangen (2008) varied the lighting conditions in the workplace of employees by exposing them to white lighting (4000 K) for four weeks and to a blue-enriched white lighting condition (17000 K) for another four weeks. Several parameters were evaluated like daily alertness, mood, sleepquality, performance, mental effort, headaches and eye strain for the duration of these 8 weeks. The data showed that blue-enriched white light improved all the tested parameters compared to normal white light. Mills Tomkins & Schlangen (2007) conducted a study within a shift-working call center. They investigated the effect on wellbeing, functioning and work performance of newly developed fluorescent light sources with a high correlated color temperature-CCT (17000 K). Results showed improved concentration for the group of employees working in that light compared to a control group; (2900K color temperature light).

Researchers have shown that people prefer different CCT depending on the activities performed in each environment. For example, people prefer different CCT in a living room when a person intends to work rather than intend to relax (Durak, Olguntürk, Yener, Güvenç & Gürçinar, 2007, Park, Chang, Kim, Jeong & Choi, 2010). Because of this variety of lighting conditions which are needed for a room, the same researchers suggest to build transformable lighting systems. These lighting systems would have the ability to change manually according to the needs of their usere.g. relaxation, arousal.

Chellappa, Steiner, Blattner, Oelhafen, Götz & Cajochen (2011), reported comparable results. In their experiment, individuals from different Swiss universities were exposed to three different lighting conditions (two types of 40 lux compact fluorescent lamps with 6500K /2500K and incandescent 40 lux lamps with 3000K), while performing tasks for sustained attention and executive functions. The results showed that exposure into fluorescent lamps, led to significantly faster reaction times in tasks associated with sustained attention, but not in executive function tasks.

The combined effects of color temperature and luminance on visual response and mood were examined by Ji-Hyun, Jin Woo & Sooyoung (2014). Participants had to perform computer and paper-reading tasks and the results showed that high luminance lighting conditions correlated with visual discomfort which influenced their mood.

Another study by Smolders, de Kort and Cluitmans (2012) showed that more intense light can improve feelings of alertness and vitality, as well as objective performance and physiological arousal in workplaces.

From all the previously mentioned works we can conclude that color temperatures plays also an important role in finding the more appropriate lighting conditions for workplace. It is also evidenced that different cognitive tasks such as sustained attention and problem solving, require different lighting conditions in order to increase performance. Knez (1995) conducted a series of experiments in order to investigate the effect of indoor lighting in problem solving tasks and long term memory. He varied two lighting parameters; luminance level (dim, 300 lx, 50 lx and bright 1500 lx) and color temperature (warm white, 3000K and cool white, 4000K). Results showed that problem solving and long term memory performances were significant enhanced in the warm white light source compare to cold white conditions.

Later, Knez (2001) conducted a series of experiments, in order to find the relationship between performance in cognitive tasks and the lighting color (reddish or bluish). The participants did a short term memory recall task, a long term memory recall task and a problem solving task. The reddish lighting condition were 3000 K, and the bluish, 4000 K. Results showed that performance in short term memory tasks was better under reddish lighting conditions. As for problem solving and long term memory, no significant results were found. At last, the author points out that women are more sensitive in lighting changes though it is difficult for him to explain why this is happening (Knez, 1995, Knez, 2001). In addition, Helson & Lansford (as mentioned in Whitfield& Wiltshire, 1990) support that there are differences in color preference according to sex males prefer cool colors while women find more pleasant warm colors. On the other hand, Granger (as mentioned in Whitfield& Wiltshire, 1990) did not confirm Helson & Lansford's hypothesis.

Kwallek and his colleagues (as it mentioned in Stone, 2001), also confirm the hypothesis that different lighting conditions enhance performance in different types of tasks. They suggest that warm colors help people concentrate better outward, meaning that it increases their perception in their surroundings, while cool colors help them concentrate more inward, meaning that it increases their sustain attention and help them stay more focus in a boring task that warm colors.

Age seems to be another factor mediating the effect of lighting conditions on performance (Knez & Kers, 2000). More specifically, older adults, aged about 65 years old have less negative mood in cool white, bluish lighting than younger adults, aged about 23 years old which have more positive mood in warm white, reddish lighting. Regarding to cognitive performance, no significant differences were found.

Stone (2001) examined the effect of lighting color (red, blue, white) on mood and performance in reading and math comprehension. The participants were adult students. Results showed that participants had better mood when they were reading in a blue environment compared to those who read in red environment. On the other hand, performance was significant lower for those who performed the reading task in the red environment. Comparing the effect of all three colors, student's performance was better in white lighting than in red and blue. Whitfield& Wiltshire'(1990) had already pointed out that in educational and working environments, blue shades in the lighting are preferable for those who work in these places.

Winterbottom & Wilkins (2009) examined a sample of UK schools in order to determine if the lighting conditions were suitable for a learning environment. The researchers assessed the average luminance of 90 classrooms for the desks surface, the projector screen and the light of the lamps during the lesson hours. Results showed that high contrast between those surfaces causes headaches and discomfort among students.

Samani & Samani (2012) also found a strong correlation between student's performance and classroom lighting conditions. Moreover, they confirmed that insufficient lighting conditions lead to health problems. On the other hand, increasing the lighting quality, improved motivation, efficiency and alertness of students.

Juslén, Woutersb & Tenner (2007) allowed industry workers to change the lighting conditions in their office. Apart from the usual light condition (100- 380 lux) they could also switch on additional lamps with 3000 lux. Results showed that those who changed their lighting conditions more often and were working with higher luminance, improved their efficiency in their work tasks. A relative experiment took place from Veitch & Newsham (2000). The majority of participants preferred to work in high luminance offices. Nonetheless, they tended to choose lighting conditions which were consistent with the standard lighting they were used to work.

In the meantime, Boyce et al. (2006) found that when employees have the ability to change their lighting conditions during the day have better mood, comfort and satisfaction compared to those who did not. They did not find an improvement in performance but because of the improvement of mood, comfort and satisfaction, researchers expect after a period of time to improve also performance. In a similar experiment (Boyce et al. 2006), the participants performed cognitive tasks, timed vision test and typing and the tasks took place several times during the day. Results were similar with the first experiment. Moreover, the second experiment shows that those who did the experiment in sustain brighter lighting conditions had better performance from those who did it in darker lighting conditions. The researchers underline that lighting conditions did not have a simple direct effect on performance as it claimed in many researches. However, there are interactions with lighting conditions and mood, comfort and satisfaction which long term will improve employee's performance.

According to the review study of Juslén & Tenner (2005), changing light environments is beneficial for both efficiency and alertness in workplaces. More specifically, changing from low to high lighting conditions seems to improve performance. The authors concluded that there are several mechanisms related with the lighting conditions that affect the performance of a person in a working environment. These factors include: visual performance, comfort, ambience, interpersonal relationships, biological clock, stimulation, job satisfaction, and problem solving.

Küller, Ballal, Laike, Mikellides, & Tonello, (2006) examined the impact of light –color, luminance and intensity- in employees mood in real work environments in different countries - situated far north of the equator and closer to the equator. Results showed that lighting intensity, and color play an important role in employee's mood across countries. The employee's mood was at the lowest level when the light was experienced as much as dark, the employee's mood was at the lowest level. On the other hand, employees mood was at the highest level when the room was high lighting but not too bright because then the mood levels started to decrease. According to the same research, illumination seems not to have a significant role on mood.

Apart from the cognitive functions that seem to be improved in high lighting working environments, it is also useful to examine if the lighting in a work place could improve social interaction between partners. Gifford (1988) ascertain that the communication between people who already know each other encouraged more in brighter work places.

1.2 The current study

In the current study, we are to test different lighting patterns in order to develop smart and adaptable environments. Such environments will adjust illumination in order to improve cognitive performance. We primarily focus on sustained attention (i.e. the ability of the system to focus attention on a given task for a period of time) as it is greatly involved in all cognitive and learning tasks.

Simulating different lighting conditions in natural environments is both difficult and costly. For this reason we took advantage of the recently introduced low-cost virtual reality (VR) headset Oculus Rift (www.oculus.com) in order to simulate realistic 3D environments in a variety of lighting conditions.

According to Franz, Heyde & Bulthoff (2003), virtual reality simulations facilitate a completely controlled variation of spatial properties and thus allow us to evaluate architectural hypothesizes.

Our virtual 3D space was a conference auditorium capable of changing the lighting conditions as well as its geometry in real time. The whole design is architecturally plausible and at the present study we focus only on the effect of the lighting parameters of the space.

We used the Unity Gaming engine (www.unity3d.com) connected with the Oculus Rift Development Kit 2 to simulate the 3D space. We designed two experiments with three light conditions: a high luminance, a low luminance and a real time altering luminance.

In the first experiment we used very subtle changes in the lighting conditions and the actual task was also real pre-recorded video lecture in order to simulate a naturalistic framework. In the second experiment we used a more controlled task with more extreme changes in lighting conditions in order to measure the strongest possible effects. This task was a short term memory recognition task of pseudo words. The same task was used in the third and the fourth experiment. In the third experiment we examined the effect of color in sustained attention and memory with two conditions, one extreme blue and one extreme red.

Finally, in our last experiment we examined the difference between real and virtual environments. Heydarian, Carneiro, Gerber, Becerik-Gerber, Hayes & Wood (2015) did comparable experiment, comparing the performance in cognitive tasks, in high luminance and low luminance conditions in a real and in a virtual environment. They used exactly the same office environment for real and virtual conditions and examined the participants in simple office tasks such as comprehension and reading speed, color recognition and object identification task. They also used Oculus Rift DK1 Head-Mounted Display which was connected to “Microsoft Xbox Kinect” and created there virtual environment via “Vizard VR Toolkit”. Results shown that performance was statistically significantly improved for the bright conditions for both real and virtual environment.

2. Experiment 1- Sustained Attention

2.1 Method

2.1.1 Participants

The study was advertised on campus at Architecture Department, Technical University of Crete, by posting ads in the official page of the department. In the first experiment thirty- two graduate students aged 19- 27 participated. There were three conditions, high lighting, darkness and altering between the two. In the high lighting condition there were 11 participants, 4 men and 7 women all graduate students aged between 21-27 years. In the dark condition, at the beginning there were 11 participants but after analyzing the data we excluded one of them because throughout the process he pushed the wrong buttons. After all, we used the data from 10 participants, 4 men and 6 women, aged between 19- 24. One female participant at the last condition did not fill the age gap in the questionnaire.

The procedure lasted three days, from 12.00 to 18.00 o clock the first two and from 13.00 to 15.00 o clock the third day. There was an online Google document, in which the participants were enrolled and they arranged their appointment in the more comfortable hour for them, from the hours we had defined for the experiment.

2.1.2 Materials

Unity: Unity is a flexible development platform for the construction of multiplatform 3D and 2Dinteractive environments which usually is used for gaming (www.unity3d.com). This program was used for the construction of the experiment's environment, a conference auditorium. This auditorium had a big screen and five amphitheater rows of seats (see Figure 1). In this auditorium we embedded a *video* lecture which screened to the participants through the *oculus rift* device. For the current experiment we constructed three same conference auditoriums with different lighting conditions. The first auditorium was with high luminance, the second with low luminance and the third with altering luminance. The altering luminance changed smoothly from high to low luminance level in a three minutes cycle.

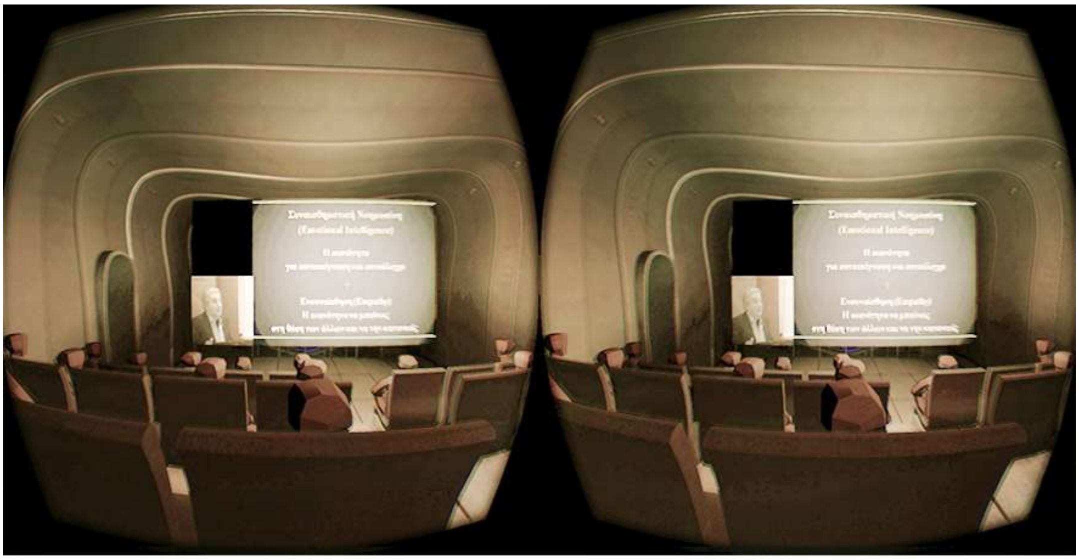

Figure 1. 3D-screenshot from the auditorium (High Luminance Condition).

Oculus rift: Through these virtual reality headsets the participants were able to interact with a 3D photorealistic model of the previously mentioned conference auditorium. Its custom optics system provides visual fidelity and a wide field of view.Oculus rift has a low latency consolation tracking system which enables the sensation of presence and as a result, the participants feel like they are indeed in the conference auditorium. As for its design, it is comfortable, customizable adaptable and lightweight device (www.oculus.com).Through this device participants had the ability to move their head and see human figures, the equipment, seats, steps, the floor and the ceiling of the auditorium. Figure 2 and 3 depict the oculus rift device.

Figure 2. Oculus rift device. (Retrieved from www.arstechnica.com).

Figure 3. Oculus rift device in use. (Retrieved from www.allgamesbeta.com).

Video lecture: The participants watched the first 21 minutes of a lecture which was retrieved from YouTube (https://www.youtube.com/watch?v=5T1Ytd_9mgs). This lecture was given by a medical professor and the topic was the emotional intelligent in the cardiology science.

Questionnaire: At the beginning of the questionnaire there were a consent form and a short description of the experiment. Then there was a likert scale in which the participants had to evaluate their relationship with the concept of emotional intelligent, their knowledge from the psychology and the medical field. The scale was fluctuated from 1 (= poor) to 5 (=excellent) (Figure 4).

1	2	3	4	5
Poor	Fair	Average	Good	Excellent

Figure 4. Likert scale

After they had watched the video, they completed also six comprehension questions with 4 suggested answers from which only one was the correct answer. E.g1 depicts a translated sample example from the comprehension Questionnaire.

E.g.1. A sample from the Questionnaire given to the participants (translated in English). According to the lecture, the correct answer is the choice number 1.

In which period of time doctors emotional intelligence is more increased?

1. When they arrive at the university.
2. Thorough their studies.
3. When they have finished their studies
4. After many years of employment in a hospital

Finally, they completed a form with their demographic characteristics, gender, age and academic level -undergraduate, graduate, doctoral and research staff-. Figure 5, depicts a screenshot from the form with the demographic characteristics.

- Προσωπικά στοιχεία:

Φύλο:	Α □ Θ □
Ηλικία:	____
Ακαδημαϊκό Επίπεδο	Προπτυχιακοί Φοιτητές □ Μεταπτυχιακοί Φοιτητές □ Διδακτορικοί Φοιτητές □ Ερευνητικό Προσωπικό □ Άλλο:__________________

Figure 5. The form of the demographic characteristics. It is the same for all experiments that follows.

2.1.3 Procedure

In the first experiment we used very subtle changes in the lighting conditions and the actual task was also real pre-recorded video lecture in order to simulate a naturalistic framework. We employed three different light variations for the auditorium; high,32% (HL), low,9% (LL), and the altering luminance that changed smoothly from high to low luminance level in a 5minute cycle (AL). The illumination for each conditions referring to average illuminations in all the surfaces except for the screen and was calculated as a percentage to the maxim illumination the oculus rift can produce.

Participants were tested individually. After reading the consent form, participants completed the likert scale in the first page of the questionnaire. They were informed not to turn the page after the scale. The experimenter then, informed them that they will watch a lecture in which every time the speaker says the target- word, they had to press the button “1” for the first and the button “2” for the second. The first target- word was the word “and” and the second the word “to” in Greek language. They had to press these buttons only when they heard the target- words (and not if they appeared on the screen). We created a ground truth[1] with the exact time the speaker said every time each word in order to compare it with the individuals answers. If they had no further questions for the task, they were asked to put on the headset and were assisted to place their index fingers onto the response buttons. When they were ready, they started watching the environment without the lecture in order to get familiar with the environment and the oculus rift device. The experimenter

[1] Ground truth is the exact time every single word appears in the screen and we used these times in order to evaluate participant’s answers.

informs them that they could watch the conference auditorium any time they wanted to before the beginning of the lecture. The sound heard from the speakers had constant volume for all individuals. Moreover, their seat into the V R environment was default. Thorough the procedure, the examiner remained silently into the room, to help the participants if anything was needed.

After the 21 minutes passed, the lecture stopped and the experimenter informed the individuals about the end of the procedure and gave them again the questionnaire, to answer the comprehensive questions and their demographic characteristics. Finally, after the individual had left, the experimenter renamed their data script with a unique code which was the same with the code into their questionnaire. There were three different conditions; the first was with high luminance, the second with low and the third the altering. The individuals did the experiment into different conditions -first individual into the first condition, second into the second, third into the third, fourth again first and so on-.

2.2 Analysis

The data analysis was performed from a custom-fit computer program that compared the answers of the participants with the ground truth. It took as input the data logged form the Unity software and computed the score for each participant. If participant's answer was within a range of +-1sec with the ground truth answer then it was counted as a hit.

The program was initially implemented with the C++ programming language using the Microsoft Visual Studio 2012 compiler. It was also used a JSON wrapper[2] to handle the data files produced from the Unity software (depicted in Figure 6). The JSON (JavaScript Object Notation) is a lightweight data-interchange format that was adopted to efficiently handle the communication between the Unity and our program. JSON it is text based which is easy for humans to read and write but also easy for machines to parse and generate (http://www.json.org/).

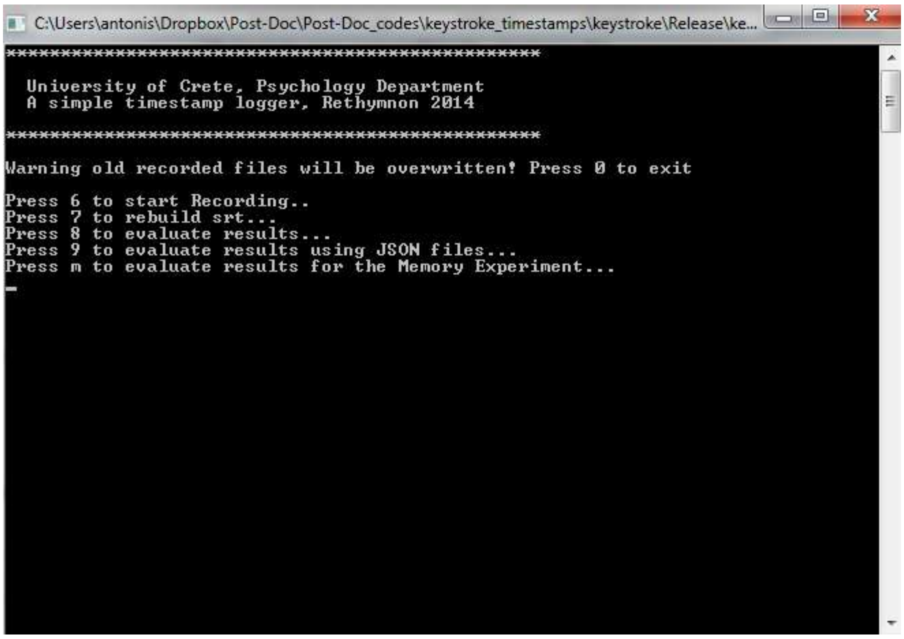

Figure 6. A screenshot from the data-analysis computer program

Our data-analysis program latter was updated to the Python language which offered more flexibility while demanding far less development time. Python is a high level computer language that lets someone to work quickly with scientific computations, easily prototype and integrate systems (https://www.python.org/).

[2]A wrapper is a small computer program that is capable of reading and transforming a data input from a specific form to another. In our case it reads and decodes the JSON files from the UNITY and passes it to our program.

The score for each subject was calculated as the sum for all the hits in all the examined target words (Total Score). The occurrences of the target words throughout the lecture were 302 in total. As for the comprehensive questions, the answers were evaluated onto an excel file.

2.3 Results

We used a one-way ANOVA to test the difference between the hits in all conditions. The average hits in each condition (HL = 112.45, LL = 113.64 and AL = 119.60) did not differ significantly and lighting conditions did not affect performance in this Experiment ($F=0.18$, $p = 0.83$). Figure 7 shows the bar plot of the means in the 3 conditions.

As for the comprehensive questions, the correct answers did not differ significantly between the three groups. The sum of the correct answers for the HL condition was 33, for LL, 38 and for AL, 32.

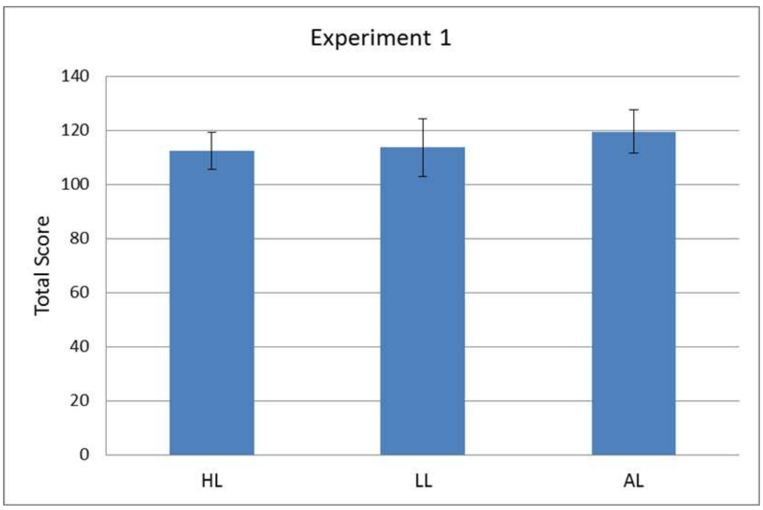

Figure 7.TotalScore from Experiment 1 (302 is the maximum achievable score).

3. Experiment 2- Sustained Attention & STM_ Extreme Conditions

3.1 Method

3.1.1 Participants

The study was advertised on campus at Architecture Department, Technical University of Crete, by posting ads in the official page of the department. Participants were 48 students and members of the research staff (19-39 years old). In each of the three conditions there participated7 men and 9 women. In the first condition –light condition- the participants were aged 19-28, 14 undergraduate students and two members of the research staff. In the second –dark condition- the individuals were aged 18-28, 10 undergraduate students, two postgraduate students, two PhD students and two members of the research staff. One female graduate student did not fill the age gap. As for the third condition –altering- there were nine graduate students and seven master students, aged 19-39 years old. All participants had normal or corrected to normal vision.

The procedure lasted four days, from 12.00 to 18.30 o clock the first day and from 13.00 to 19.00 the next three days. There was an online Google document, in which the participants were enrolled and they arranged their appointment in the more comfortable hour for them, from the hours we had defined for the experiment.

3.1.2 Materials

Both Unity and Oculus rift are used for the same reasons as previously mentioned in the second chapter. It also used a demographic characteristics questionnaire, which was given to the participants after the procedure.

3.1.3 Procedure

In experiment 2 we changed the lighting conditions and the task. We create a more controlled task and less naturalistic environment in contrast with the first experiment, with a view to establish the existence of the effect of light in sustained attention.

We increased the difference in lighting having a condition with extreme high luminance, 61% (XHL) (Figure 8), one with extreme low, 7% (XLL) (Figure 9) and one altering (XAL) between the previous extreme conditions every 15 sec in smooth cycles.

The task was inspired from Lapointe's (2013) and Jones & Oberauer's (2013) experiments. Participants had to perform a short-term memory task. Seven pseudo-words were presented one at a time for 800ms each. Subsequently participants performed a recognition task where they picked the stimuli they had seen from a new list with 3 target and 7 distractor words. Fifteen total trials were run for each participant and a correct recognition score was calculated from all trials. The maximum achievable score was 150 (10_{words} x 15_{trials}).

After the participants came into the lab, the experimenter show them were to sit and gave them a paper with instructions. After finishing the reading, the experimenter repeated the instructions orally in order to make sure that the participants consolidated what should they do. Subsequently, the experimenter helped them to wear the oculus rift device, adjust the helmet in each participant head size and arrange the first two fingers in the two answer buttons.

At this time they were seeing a total black environment via oculus rift. When they were ready, the experimenter pressed the space button and after five seconds, the environment appeared on the screen. At the beginning of every trial, there was a slide with instruction for 15 sec and after that it appeared a slide with the symbol "+" for 800ms to prepare for memorizing the seven words that will follow. The seven pseudo-words appears one after the other and each one stays in the screen for 800ms. After the seventh word, in the screen appears a mask [**xxxxx**] for 5 seconds to eliminate the effect in sensor memory. When the examination part began, the individual had 2 sec in order to answer if the word in the screen was in the learning list or not. If it was, he/she pushed the number button "1" and if not, the number button "2".If the time limit of two seconds for each word passed without no button, the slide changed automatically to the next word. The same procedure was repeated for 15 trials for every individual.

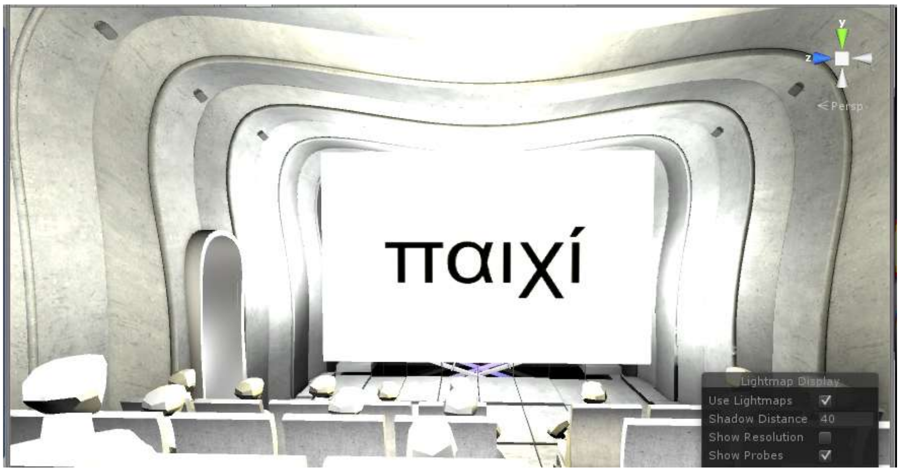

Figure 8. XHL condition in Experiment 2

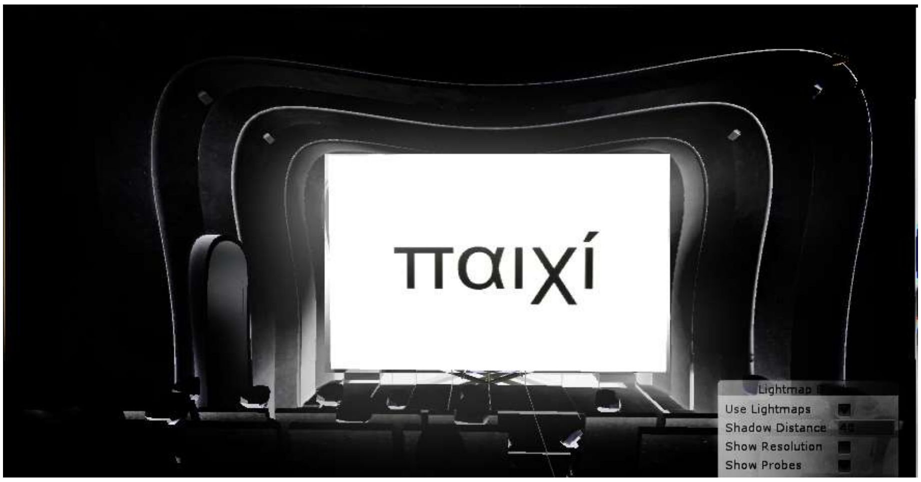

Figure 9. XLL condition in Experiment 2

3.2 Analysis

The data analysis performed from the same custom-fit computer program that described in the Section 2.2.

We also tried to verify if there were changes in the participant's attention between the first seven and the last seven trials. From this analysis, we excluded the data from the first trial in order to have equal number of trials to split the trials in half. Moreover, this happens because the experimenter, who was inside the room when the experiment took place, observed that in the first trial, the subjects made mistakes because they needed more time to get familiar with the procedure. So, in this analysis we split the data from the light condition in two groups for each participant (XHL1 for the first seven and XHL2 for the last seven trials) and compared these two groups. Equally happens with the dark condition (XLL1 for the first seven and XLL2 for the last seven trials).

3.3 Results

Figure 10 shows the data for Experiment 2. A one-way ANOVA showed a significant effect of lighting ($F=4.19$ and $p=0.021$) and post hoc T-tests were used to evaluate differences between all conditions.

Correct recognition was highest for the XHL condition (90.26). This was significantly higher than performance in the XLL condition (71.25), $t(15) = 2.74$, $p = 0.014$, and from the XAL condition (76.25), $t(15) = 2.37$, $p = 0.031$. XLL and XAL did not differ significantly; $t(15) = -0.69$, $p = 0.050$.

As for the correlation within the conditions, no statistically significant results found. XHL1= 40.37, XHL2= 45.12, XLL1= 30.5 and XLL2= 38.

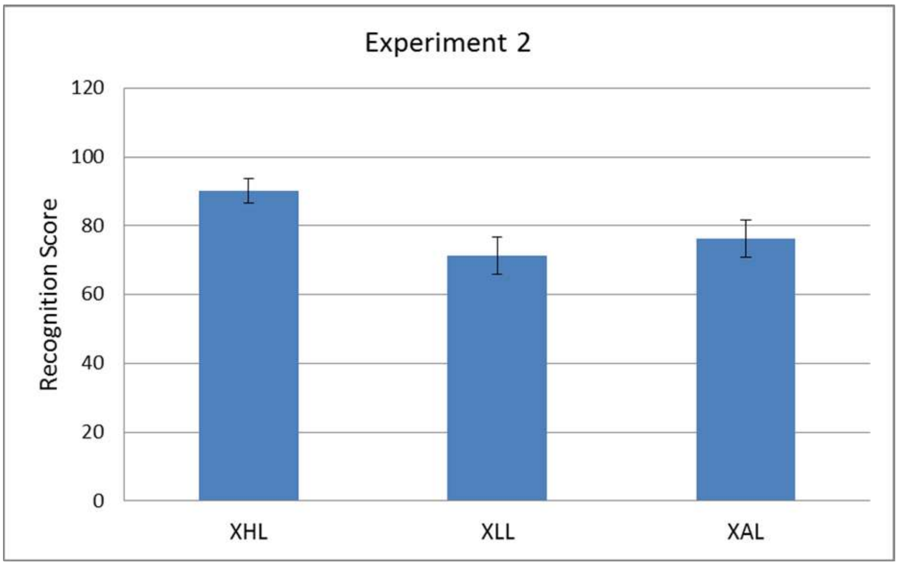

Figure 10. Correct Recognition Scores from Experiment 2

4. Experiment 3- Sustained Attention & STM_ Color

4.1 Method

4.1.1 Participants

The study was advertised on campus at Architecture Department, Technical University of Crete, by posting ads in the official page of the department. In the current experiment, the participants were 25, 13 in the blue (Figure 11) condition and 12 in the red (Figure 12). There were 4 men and 9 women in the blue condition, 10 undergraduate students, one PhD student and two members of the research staff, aged 19- 30 years old. In the red condition there were six men and six women, aged 19-30 years old, 10 undergraduate students and one postgraduate student. One male participant in the red condition did not fill the academic status gap. All participants had normal or corrected to normal vision.

The procedure lasted two days, from 12.30to 16.30 o clock the first day, 25/05/2015 and from 11.45 to 14.45 o clock the second day, 28/05/2015. There was an online Google document, in which the participants were enrolled and they arranged their appointment in the more comfortable hour for them, from the hours we had defined for the experiment. The appointments were scheduled every quarter.

Figure 11. Blue condition in Experiment 3

Figure 12. Red condition in Experiment 3

4.1.2 Materials &Procedure

Materials were the same with the previous mentioned experiments. We also followed exactly the same procedure with the second experiment.

4.2 Analysis & Results

The data analysis performed from the same custom-fit computer program that described in the 2.2.

We used a one-way ANOVA to test the difference between the hits in the two conditions. The average hits in each condition (blue= 90.46 and red= 85.17) did not differ significantly and lighting conditions did not affect performance in this Experiment (t=0.57, p = 0.57). Figure 13 shows the bar plot of the means in the 2 conditions.

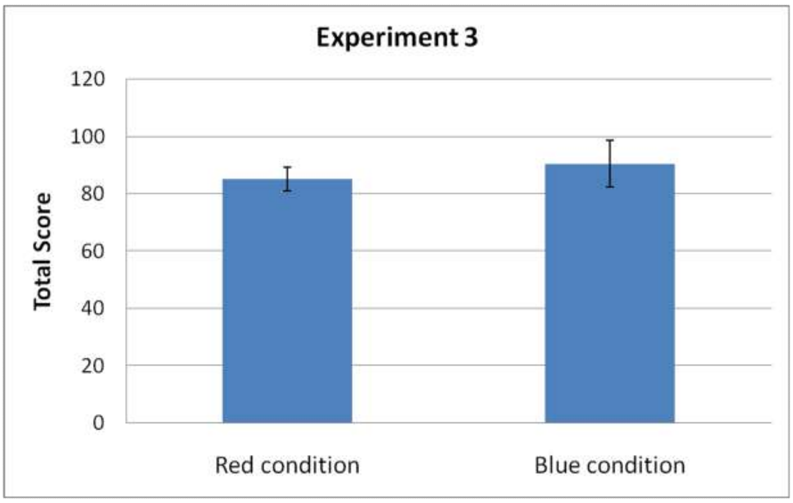

Figure 13. Correct Recognition Scores from Experiment 3

5. Experiment 4- Virtual vs Real life

5.1 Method

5.1.1 Participants

In this experiment, the participants were all undergraduate students of the University of Crete, department of Psychology. We informed them about the experiment by posting ads in the official Facebook page of the department. The majority of them were enrolled in a cognitive psychology lesson course and received course credit for the participation in the experiment. The participants were 34, 17 in each condition and their age ranged between 19- 22 years. In the first condition –light condition- there were 3 men and 14women and in the second –dark condition-, 1 man and 16 women. There was also one female participant who did not finish the procedure and so we replaced her with another participant.

The procedure lasted two days, from 11.30 to 15.00 o clock the first day, 27/05/2015 and from 10.30 to 14.30 o clock the second day, 29/05/2015.

5.1.2 Materials

We designed the short term memory experiment via the program Super Lab 4.5 in order to examine the effect which found in the second experiment via virtual reality in real life.

Projector: To display the slides, we used a projector XD1270D. For the dark condition, brightness was 0 and contrast 59. As for the light condition, brightness was 75 and contrast 59.

Seat: The participants sat 2.80 meters from the projector image

Lights: Two constant video lights. Each video light was powered by 135W/5500K fluorescent lamp housed in a 50x70cm soft box. Both light heads were faced towards the ceiling to provide a uniform lighting.

Photometer: All luminance were measured by a Konika Minolta LS110 photometer.

5.1.3 Procedure

The experiment took place in the dark room in the experimental psychology lab. The procedure was similar with experiment's two. Because of the lack of light equipment, it was impossible to reenact the altering light condition, so we run the experiment for the high and low luminance condition. The briefing took place outside the dark room, in chairs that were placed in a shady spot. After they came into the dark room, the experimenters showed them the buttons the two answer buttons – the button "1" if they have seen the word and the button "2" if not. The projector was in the first slide with the instructions and in contrast with the oculus rift experiments, they had as time they wanted to read them before they push the space button to start each of the 15 trials. Throughout the procedure, the experimenter was in the waiting area, briefing the next subject. At this point, it is worth noting that the room was soundproofing, so the subjects were isolated from the outside environment.

After they finished the experiment, the participants completed the form with their demographic characteristics, gender, age and academic level and gave it to the experimenter, who wrote their code number, to identify their demographic characteristics with their data. Before the next participant came in, the experimenter changed the lighting conditions. In the high luminance condition changed the projector adjustments and turn on the lights while in the low luminance, changed the projector adjustments and switch off the lights.

5.2 Analysis & Results

The maximum achievable score was 150 (10_{words} x 15_{trials}). The analysis was conducted via Super Lab.

No statistically significant results were found between the two groups. The mean of the extreme high luminance condition was 117.52 and for the extreme low luminance condition 110.11 (Figure 14). Additionally, the results are not in agreement with the results of the second experiment.

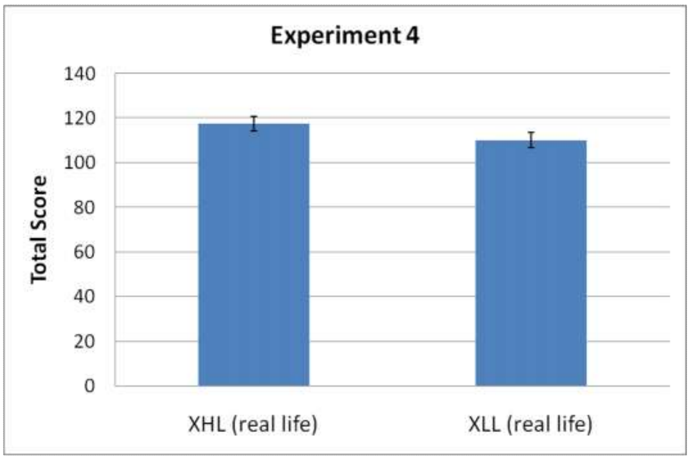

Figure 14. Correct Recognition Scores from Experiment 3

6. Conclusions

Our results generally agree with the previous research and also offer some insight for the specific effect of lighting characteristics in virtual and real life environments.

Our results indicate that memory improves under a high illumination condition compared to both low and alternating illumination condition. The absence of a difference between the latter two conditions is surprising as the low illumination condition was generally sub-optimal compared to any other condition. Thus, one would expect that low illumination condition to hinder performance the most. Perhaps the fast change employed distracted our observers and we plan to test smoother illumination alternation cycles in subsequent experiments. Taken together with the results from Experiment 1, our data could also suggest that in order to test the effect of lighting on cognitive tasks, one would need to utilize large differences in illumination levels, at least when using a VR simulation.

Additionally, the more tightly controlled tasks such as Experiment 2,3, and 4 compared to more naturalistic ones such as Experiment1 are more likely to reveal differences between lighting conditions in VR environments.

Our results generally confirm previous research that has shown a correlation between lighting and performance favoring high illuminations over low ones.

While illumination is strongly related with performance in real working environments this relationship might be weaker in artificial environments. This assumption according to Experiment 4 is not confirmed. There could be some hypotheses why this happens. First of all, there were differences in the environment architecture, as the layout and the size of the room. It is possible that the geometry of an environment plays also a fundamental role in cognitive functions. This is a hypothesis that has to be checked in a future study. Moreover, it is likely that the lighting conditions were not as extreme as in Experiment 2. The way in which the lighting was measured was different between the real and the artificial environment and for that reason it is difficult to say if the lighting conditions were equal. There is also a hypothesis that may explain the conflicting results of Experiments 2 and 4. The human perceptual system, evolutionary, it is possible trained to absurd the changes in lighting conditions. The artificial environment via oculus rift in which the participants examined in Experiment 2 is a new type of environment and maybe the perceptual system has to do all the proceedings from the beginning, without the evolutionary patterns that are learned.

A second question concerns the exact nature of the effect lighting has on performance. The improvement observed in our task could be a direct effect of high illumination on memory encoding, retrieval processes, or underlying attentional allocation mechanisms. Separate tests need to be done to distinguish between these hypotheses in order to gain a better insight at designing optimal smart transformable learning environments.

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