

The impact of greenery and daylight on productivity and well-being at the workplace: An Experimental Case Study

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Abstract

The improvement of productivity in a work environment brings significant economic benefits, and greenery and daylight's effect on productivity, creativity, and well-being is notable, providing an efficient method of regulating the indoor environmental conditions within buildings. Greenery and daylight can potentially lead to performance gains for the organization and a reduction in instances of absenteeism, and increasing well-being, creativity, and productivity among the workforce. This, certainly, would improve value added of Facility Managers performance and would help Europe and Japan to carry on their economic momentum. As a result, the proposed combination of greenery and daylight contributes to increasing productivity, creativity and well-being of employees.

Keywords: Facility Management, Workplace, Productivity, Health, Well-being.

Introduction

According to 2015 report, Japan passed the tipping point at which its population began to decline in 2011 (Ministry of Health, Labor and Welfare 2012). By 2040, more than one-third of its population will be 65 years old or older (Marutschke 2017). The implications of this shift can be felt already economically and socially. With its working-age population shrinking, Japan has to focus on productivity as the primary catalyst for economic momentum.

With well-being and productivity at the workplace as economic and social critical factors, the purpose of this experiment is to investigate office users' perceptions and the effect on productivity, creativity, and well-being of their working environment in the relation of greenery and daylight as variables.

Users' perceptions are examined using a questionnaire and measuring physical and physiological parameters, administered to two experimental groups and a control group before and after the installation of greenery and daylight. The results are analyzed to determine any statistically significant differences between the three groups and between the pre- and post-test subjective. Furthermore, daily tests are undertaken for temperature, relative humidity, CO₂, and luminance.

1. Experiment Outline

1.1 Outline of the subject experiment

The experiment with subjects is carried out in a laboratory environment of Taisei Company (Fig. 1) for a total of five days from February 13th to 17th 2017. We characterized one control group and two experimental groups as follows: subjects are a total of eight male, college students, with a standard body type ($18.5 < \text{Body Mass Index (kg/m}^2) < 25.0$) without smoking habits. In this study case, we perform a series of tasks simulating office work, with a totalling three task set in the morning and three in the afternoon (Fig. 3). During simulation work, text typing is done as information processing work, and mind map as knowledge creation work. This study is done under the protocol approved by the bioethics research committee of Faculty of Science and Technology, Keio University (No.28-19).



Fig. 1a: Interior of the experimental place with greenery.

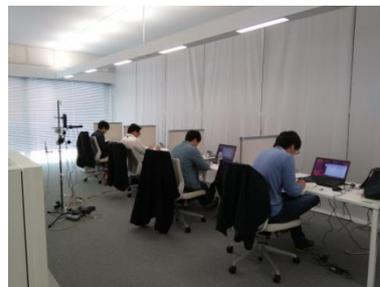


Fig. 1b: Interior of the experimental place without greenery.

The typical daily experimental schedule is shown in Figure 2. The subjects are set in the simulated environment at 9:00. Firstly, they respond a questionnaire on the eve-morning activities. After that, a 60 minutes' session starts, with physiological measurement, questionnaire and simulated work with two different tasks, performed in 25 minutes each one. Before and after the experiment subjects enjoy free time, however, strenuous exercise or drinking alcohol are prohibited.

It has been demonstrated that productivity decreases when the end time is close. Task Set three is added with the aim of not compromising the results of Task Set one and two, and results of Task Set three are not taken into account, eliminating the "end time effect" (Diehl 1991).

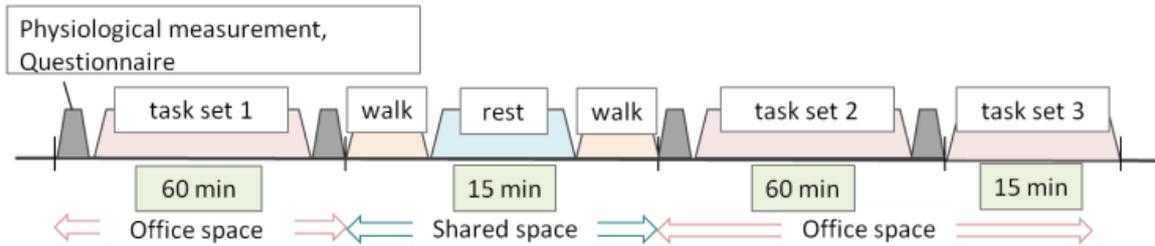


Fig. 3: Morning and afternoon schedule.

1.2 Case setting

As shown in Table 1, during the five days in which the experiment is developed, three cases are established, combining the presence of daylight and greenery.

Tab. 1: Experiment cases setup combining the total of three cases. Each case combines greenery and daylight as variables.

		2/13 (M)	2/14 (T)	2/15 (W)	2/16 (T)	2/17 (F)
Group A	Subject 1	CASE 1	CASE 1	CASE 2	CASE 3	CASE 3
	Subject 2	No Daylight	No Daylight	No Daylight	There is	There is
	Subject 3	No Greenery	No Greenery	There is	Daylight	Daylight
	Subject 4			Greenery	There is	There is
Group B	Subject 5	CASE 3	CASE 3	CASE 3	CASE 1	CASE 2
	Subject 6	There is	There is	There is	No Daylight	No Daylight
	Subject 7	Daylight	Daylight	Daylight	No Greenery	There is
	Subject 8	There is	There is	There is		Greenery

In Case 2 and Case 3, are placed four units of *Dracaena Lemon Lime*, four units of *Sansevieria Trifasciata* (Snake plant) and four units of *Aloe Vera*. Figure 2 shows the exact location of the greenery. The plants are selected according to the classification made by the NASA study of plants with particular qualities regarding air purification (Wolverton 1989). Table 2 summarizes the main characteristics of the selected plants.

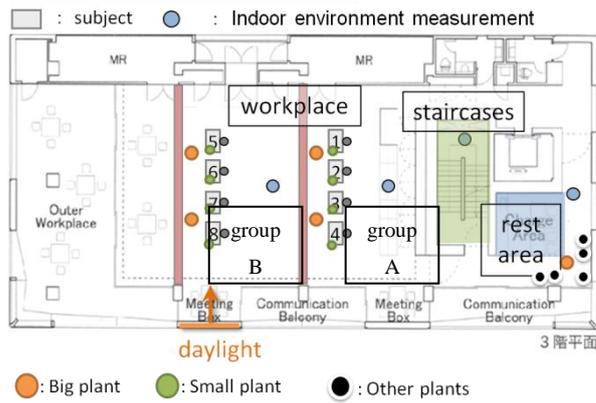


Fig. 2: Experiment place layout.

Tab. 2: Selected greenery.

Name	Dracaena Lemon Lime	Sansevieria Trifasciata	Aloe Vera
Size	Large	Large	Small
Contaminants it eliminates	Trichloroethylene, Formaldehyde, Xylene	Trichloroethylene, Formaldehyde, Benzene, Ammonia	Formaldehyde, Benzene
Picture			

About the rest time area, two cases are set: a case in which students rest at the desk for 15 minutes and another instance where students go for a walk from the workspace to the rest area for repose (Saurabh 2015), and which is provided with greenery and daylight.

In the analysis of the results of the experiment, daylight and greenery are not combined, in order to study the effect of both variables separately.

1.3 Measurement item

(1) Indoor environment

A continuous measurement of the ambient temperature, relative humidity, globe temperature and wind speed is made at the height of 1.1 meters from the floor plane. Likewise, the noise and CO₂ concentration are measured at 20-minute intervals and the luminance on the work surface and vertical surface at the beginning of each work session. The average value of the CO₂ concentration is 886 (±105) [ppm], the noise is 49.9 (±1.2) [dB], the luminance at the

horizontal plane is 503.5 (± 15) [lx]. According to Hygienic Environment in Buildings regulations, the interior of the office is in standard condition. Table 3 shows the results obtained.

Tab. 3: Indoor Environment Measurement results during the experiment (\pm Standard Deviation).

Group	Morning		Afternoon	
	A	B	A	B
1.1m Temperature [$^{\circ}$ C]	24.4 \pm 0.4	25.0 \pm 0.4	24.6 \pm 0.5	24.6 \pm 0.4
Humidity [%]	38.1 \pm 2.7	37.5 \pm 3.0	40.0 \pm 2.0	40.5 \pm 2.3
Wind speed[m/s]	0.13 \pm 0.08	0.15 \pm 0.07	0.13 \pm 0.08	0.14 \pm 0.06
Globe Temperature[$^{\circ}$ C]	24.1 \pm 0.4	24.9 \pm 0.4	24.2 \pm 0.4	24.4 \pm 0.3
CO ₂ concentration[ppm]	832 \pm 100	842 \pm 105	939 \pm 109	954 \pm 127
Noise[dB]	50.1 \pm 1.5	48.6 \pm 0.9	49.7 \pm 0.9	48.6 \pm 1.2
Horizontal plane Luminance [lx]	455 \pm 22	1032 \pm 303	425 \pm 8	477 \pm 57
Vertical plane Luminance [lx]	232 \pm 122	603 \pm 117	211 \pm 106	321 \pm 39

(2) Physiological measurement

Heart rate, salivary amylase concentration, tympanic membrane temperature and activity level are measured during the experiment. Continuous measurement of heartbeat is carried out to ascertain the change of autonomic nerve state which is an index of stress at work and the relaxation state and the sympathetic activity during work. The salivary amylase concentration is measured in order to grasp the stress state before and after work. Also, the tympanic membrane temperature is measured for physical condition control of subjects. Also, intending to seize the subjects' routine that is out of the experimental time, the activity amount is continuously measured.

(3) Psychological measurement

The indoor environment satisfaction degree is evaluated in six-grade scale: thermal comfort, light, noise, air quality and space environment of workplace and rest area. Physical condition, fatigue, drowsiness, subjective work efficiency before and after work are also studied. Therefore, subjective symptom investigation is also used for evaluating fatigue perception. Finally, subjective workload evaluation is performed using the Japanese version of NASA Task Load Index (Hart 1988).

2. The relationship between Greenery and Productivity

For the unification of conditions, according to the questionnaire of the morning, we exclude those who are in severe physical condition, those who had drunk the night before and those who did not take breakfast. A positive correlation is found for physical health, drinking alcohol, and breakfast with tasks results. Also, since the influences of hunger and fatigue in the morning and afternoon are different, we analyze each result separately. Table 4 shows the most significant factors correlated with the presence of greenery in the workplace.

Tab. 4: Correlation analysis result of satisfaction about greenery degree and psychological quantity.

"Was thermal sensation adequate?"	0.560**
"Do you feel tired?"	0.490**

** p< 0.01 (bilateral). N= 27

2.1 Influence of utilization of Greenery on stress condition

The results of the saliva amylase concentration after working in space with greenery and in the space without greenery are shown in Figure 4. By measuring the saliva amylase concentration is possible to understand the stress state at that time. There is a significant difference between cases in the morning and afternoon. The result suggests that the use of greenery in the office space would affect the stress condition.

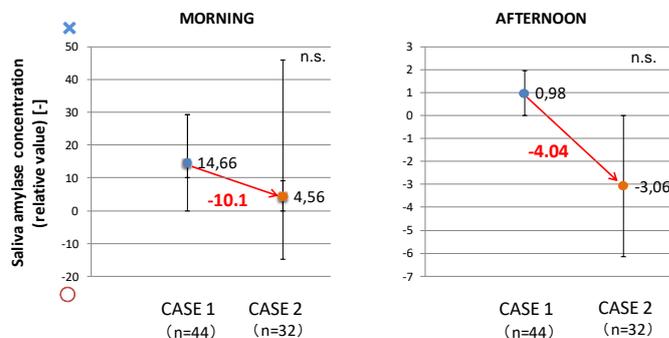


Fig. 4: Saliva amylase concentration in each case.

2.2 Psychological influence on the use of Greenery

Before the experiment, during the recruitment period, students were asked about possible allergies to plants, selecting only people who did not present any pathology. During the five days in which the experiment is carried out, the groups of people who occupy the workspace with greenery are asked about their satisfaction with them. Figure 5 shows that 71.4% of the people said they were satisfied or very satisfied with greenery.

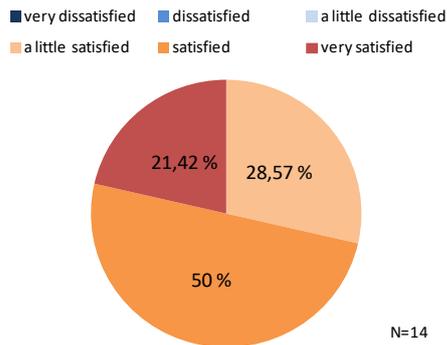


Fig. 5: Satisfaction about greenery questionnaire.

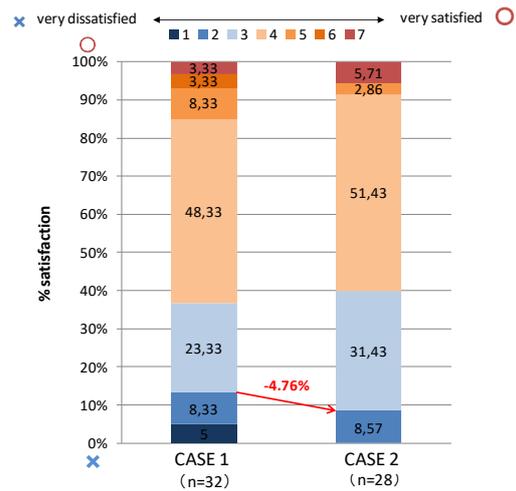


Fig. 6: Answer percentages to the question: "Did you feel thermal sensation adequate?"

2.3 The relationship between Greenery and thermal satisfaction

The thermal sensation is strongly correlated with the presence or not of greenery in the workplace. It is important to note that the two groups are under the same ambient temperature conditions. According to the answers obtained in the questionnaire, mention should be made of the decrease in the percentage of "dissatisfied" and "very dissatisfied."

2.4 The relationship between Greenery and fatigue

There is a significant correlation between the presence of greenery and the subjective feeling of tiredness manifested in the Jikaku-sho Shirabe questionnaire. The percentage of people who feel "tired" or "very tired" descends significantly in the case with the presence of greenery, highlighting the decrease of that percentage by 15.5% in the morning.

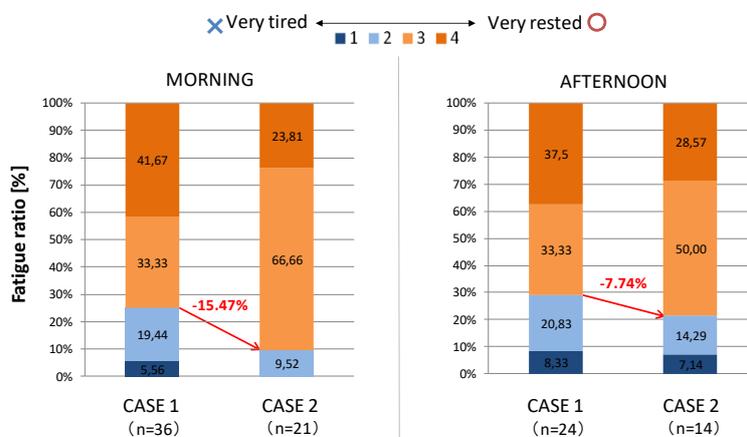


Fig. 7: Fatigue reporting ratio.

2.5 The relationship between Greenery and intellectual productivity

The results of the tasks are analyzed, noting that none of the eight subjects show abnormal productivity results.

Figure 8 shows the erroneous batting typing rate with and without greenery use in the workplace, and Figure 9 illustrates the number of valid responses in the mind map task. Results are normalized and analyzed to eliminate individual ability differences. Furthermore, the results of the first day are excluded, taking into consideration the effect of the inexperience. The task results are not significantly different between cases in the morning or afternoon. Although the presence of greenery in the workplace does not contribute to the enhancement of the work efficiency, it is necessary to point out that other factors could affect the result, such as the lack of space illumination.

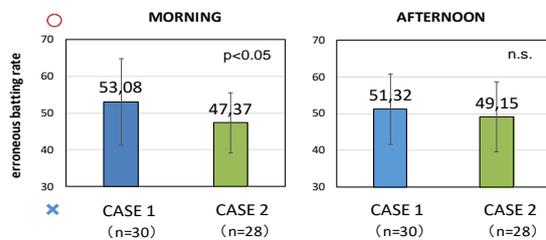


Fig. 8: Results of typing task in each case.

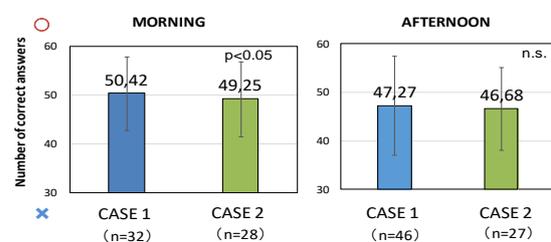


Fig. 9: Results of mind map task in each case.

3. The relationship between Daylight and Productivity

In this paper, we quantitatively verify the relationship between daylight utilization and fatigue feeling, sleepiness and intellectual productivity. Following the same criteria as in the analysis of the relationship between the presence of greenery and productivity, for the unification of conditions, according to the questionnaire of the morning, we exclude those who are in severe physical condition, those who had drunk the night before and those who did not take breakfast. Also, since the influences of hunger and fatigue in the morning and afternoon are different, we analyze each result separately.

3.1 The relationship between Daylight and luminance

According to the results shown in Table 3, it is confirmed that there is no difference in thermal, air quality and sound environment in the presence or absence of daylight. Similarly, it is confirmed that the light environment (horizontal surface and vertical surface luminance) is brought to high luminance by using daylight. Furthermore, Fig. 10 shows the desk top luminance which is thought to affect the work performance. It is 577lx higher in the morning

and 52lx higher in the afternoon ($p < 0.01$) in daylight utilization space compared with no daylight use space. It is confirmed that the luminance on the desk top surface is significantly higher than usual, especially on morning.

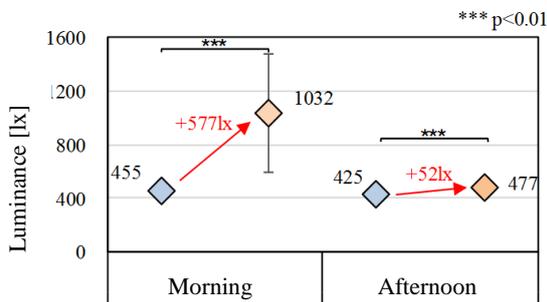


Fig. 10: Measurement result of desk top luminance during experiment

3.2 Effect of utilization of Daylight on the Sympathetic nerve

The relationship between the Sympathetic Activity Low Frequency (LF) / High Frequency (HF) during working and the workspace with and without daylight is analyzed. The difference from the resting value of each day for each subject is calculated and taken as a relative value to eliminate individual differences between days. Moreover, we exclude the day indication where the sympathetic state at rest is abnormal. It is thought that it is desirable that sympathetic nerves be active and in a state of awakening during work (Oyama 2015). As Figure 11 shows, sympathetic activity is 0.25 pt higher ($p < 0.10$) in the morning and 0.26 pt higher in the afternoon ($p < 0.05$) than in the case without daylight, compared to the case without daylight. From this, it is shown that the use of daylight to the office space could activate the sympathetic nerve during work and bring about the arousal state.

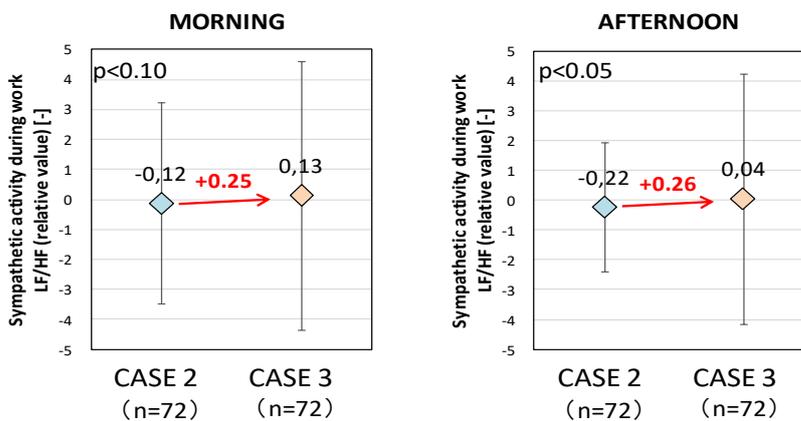


Fig. 11: Sympathetic activity during work LF/HF.

3.3 Effect of utilization of Daylight on psychological quantity

Table 5 shows the most significant factors correlated with the presence of daylight in the workplace. The higher the degree of satisfaction with the light environment, the more likely it is that there is a correlation with a capacity of concentration, fatigue, work efficiency, and motivation.

Tab. 5: Correlation analysis result of presence of daylight and psychological quantity

Capacity of concentration (1: not possible ~ 6: very easy)	0.693**
Exhaustion Feeling (1: very tired ~ 9: not at all tired)	0.562**
Subjective work efficiency (%)	0.662**
Motivation (%)	0.692**

** $p < 0.01$ (bilateral). N= 27

3.4 Influence of Daylight presence on subjective workload

In the case of daylight utilization, the subjective workload scores are lower by 9.8 pt ($p < 0.10$) in the morning and by 13.7 pt ($p < 0.05$) in the afternoon compared with the case without daylight ($p < 0.05$). From this, it is shown that the score of the subjective workload evaluation decreases due to the use of daylight to the office workspace, and the possibility of suppressing the workload is shown.

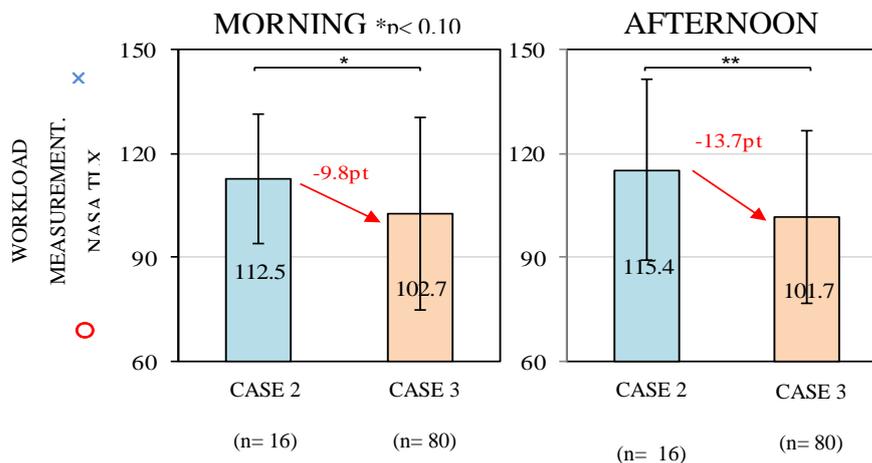


Fig. 12: Evaluation of subjective workload in each case (NASA-TLX)

3.5 The relationship between Daylight and intellectual productivity

In order to eliminate individual capacity differences, typing and mind map results are normalized and analyzed. Additionally, the results on the first day are excluded, taking into consideration the effects of unskilled work.

The erroneous batting rate of typing, which is a simple task, is not significantly different between cases in the morning and afternoon. From this, it is shown that there is no influence of the use of daylight to the office space for simple work.

Meanwhile, the number of effective responses of the mind map, which is a creative work, is 5.4 pt higher ($p < 0.05$) in the morning and 1.6 pt higher in the afternoon ($p < 0.15$). From this, it is shown that the use of daylight to the office space in the creative work could contribute to the improvement of work performance. Although the use of daylight to the office workspace does not contribute to the enhancement of the work efficiency of simple work, the possibility of contributing to the work performance of the creative work is shown from the above.

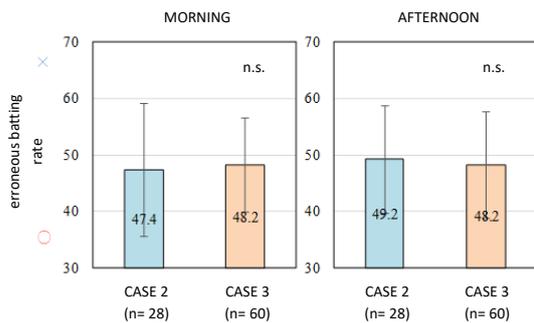


Fig. 13: Results of typing task in each case.

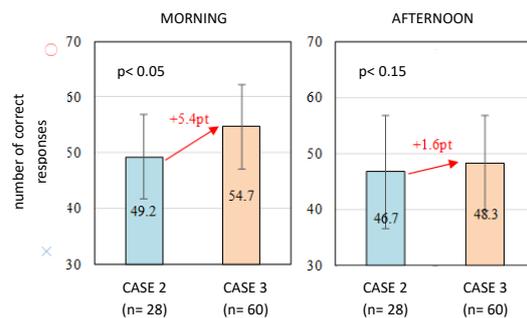


Fig. 14: Results of mind map task in each case.

4. Conclusions

In this research, subject experiments are conducted with the aim of quantitatively verifying the influence of utilization of greenery and daylight in the workplace on intellectual productivity. The findings obtained by this experiment are shown below.

- 1) The results conclude that there is a decrease in the saliva amylase concentration of up to 10.1 points, which signify an improvement in the stress condition in the case with the presence of greenery.

- 2) In the case of the presence of greenery, the percentage of people dissatisfied about thermal comfort decreases by 4.8% and the percentage of tiredness perception reduces a 15.5% on morning and a 7.7% on the afternoon.
- 3) There is a positive correlation between greenery presence and satisfaction about the thermal environment, and there is a negative correlation between greenery and subjective perception of fatigue.
- 4) The isolated presence of greenery does not present a significant difference in productivity enhancing, but it has an impact on well-being, reducing stress levels.
- 5) By using daylight in the office space, activation of sympathetic nerve at the time of work is confirmed, indicating the possibility that a state of arousal is brought.
- 6) The use of daylight in the workplace shows the possibility of reducing the fatigue feeling. Also, the satisfaction standards of the light environment could influence concentration, fatigue, motivation, and efficiency.
- 7) By using daylight to the office space, the subjective workload evaluation score using NASA-TLX is 9.8 pt lower in the morning and 13.7 pt lower in the afternoon. From this, it is shown that the use of daylight to the workplace could contribute to the reduction of the workload among the workforce.
- 8) There is no significant difference in typing erroneous batting rate between daylight utilization cases. The effective answer number of the mind map is 5.4 pt higher in the morning and 1.6 pt higher in the afternoon compared to the case without daylight in the case of daylight use. From this, it is shown that the use of daylight to the office space does not contribute to the improvement of the work efficiency of simple work but may contribute to the work performance of creative work. From the above, it is shown that the use of daylight to the office workspace could contribute to the improvement of work performance of creative work through activation of the sympathetic nerve, reduction of fatigue feeling and reduction of workload.

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6. References

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