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Study on the Operators' Attention of Different Areas in University Laboratories Based on Eye Movement Tracking Technology

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ABSTRACT To explore different operators' eye movement characteristics, which can reflect their degree of attention and hazard identification ability in university laboratories, experiments were carried out with 60 junior students. The laboratories were divided into five areas by function and hazard type. The subjects were divided into two groups based on their safety experience. Using typical university laboratory images as stimulus materials, a Tobii X2 eye tracker was used to measure and record the eye movement parameters of the subjects in five laboratory areas. The results showed that the subjects exhibited greater interest in the equipment area (attracting the focus of 100.00% of the subjects) and less interest in the wireway area (attracting the focus of 46.67% of the subjects); no significant difference was observed between subjects who were or were not specialized in safety. Most subjects could identify the hazard sources in the five areas but paid little attention to electrical sockets. Thus, countermeasures including reasonably matching the color and layout in laboratories and popularizing laboratory safety education are proposed, which will provide a basis for strengthening safety management in university laboratories.

INDEX TERMS Laboratory safety, hazard identification, eye tracker, eye movement, attention.

I. INTRODUCTION

The university laboratory is an important place for experimental teaching and scientific research. Because of the environmental hazards and occurrence of personal operation errors, accidents occasionally occur in university laboratories. Data show that 98% of university laboratory safety accidents are caused by human factors [1], [2]. Large numbers of laboratory accidents have been reported worldwide, resulting in fatalities, severe injuries and financial losses, which demonstrates that there is a significant need for better identification of laboratory hazard sources and risk management practices within academic teaching and experimental research laboratories [3].

At present, many safety evaluation and analysis methods have been used for laboratory hazard source identification, such as risk matrix analysis [4], safety checklist [5], fuzzy evaluation and hazard evaluation and risk analysis. These methods are mainly based on identifying unsafe objects and formulating corresponding laboratory safety management measures. However, these methods usually include strong subjective factors. Additionally, there is still no typical laboratory hazard identification method from a human cognition perspective because the man-machine system includes many uncertain factors with regard to humans, such as psychological factors, physiological factors, health conditions and educational level [6]. These factors impact individual judgment of risk factors.

Eye movement tracking technology is an emerging method that can be used to observe and record eye movement parameters and measure the visual reaction, attention concentration ability and attention distribution. Therefore, the subjective influence of the observer can be effectively eliminated. Eye movement tracking technology has been widely used in the fields of man-machine interaction, pedagogy, psychology, advertising and web design [7]. Terenzi *et al.* [8] explored the influence of space and position information on the layout design of interfaces using the Tobii eye movement

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TABLE 1. The division of laboratory areas.

Region	Number	Main hazard source
Medicine area	*A*	Chemical agent, etc.
Equipment area	*B*	Ventilation equipment, electrical equipment， reaction equipment, etc.
Container area	*C*	All kinds of containers, Gas cylinders, etc.
Wireway area	*D*	Wire, socket, etc.
Sign area	*E*	All kinds of signs, Management regulations, etc.

instrument. They found that the expectation of users regarding the arrangement of the location of web page elements is based not only on the spatial position of the objects, but also on the actions when the objects are placed. Balk *et al.* [9] studied the effect of mobile phone use on driving performance during simulated driving behavior with the Tobii eye movement instrument. He defined the driver's observation of the target in the driving process using the line of sight trajectory.

Currently, eye movement tracking technology is not widely used in the field of safety, especially in laboratory hazard identification research. Therefore, the eye tracking experimental module in the Ergo LAB man-machine environment synchronization platform was used in this study to measure the eye movement characteristics of different subjects so that their diverse observation and attention patterns to various regions of a university laboratory can be better understood. This will be very helpful for safety management in university laboratories.

II. METHOD

A. PARTICIPANTS

40 junior students (including 20 male and 20 female) who are major in safety engineering were selected, and their average age is 21. 40 not safety specialized junior students (including 20 male and 20 female) were selected, also their average age is 21. All these subjects are from the same university, and they all have experiment experience. They have healthy eyes (visual acuity level $\geq$5.0, no color vision problem), similar height, and have no previous mental or neurological problems.

B. APPARATUS AND STIMULI

Liquid crystal display, 1440 $\times$ 900, Lenovo L197WF, China; Eye tracker, Ergo LAB man-machine environment synchronization platform, eye movement tracking experiment module, Tobii X2-30, Sweden.

The typical university laboratory, including chemical laboratory, equipment laboratory and basic physical laboratory were selected as the research objects. The laboratories were divided into five regions according to their function, they are medicine area, equipment area, container area, wireway area, sign area, as it is shown in table 1. Name these laboratory regions A, B, C, D and E, respectively.

The laboratory regions' images were imported into the Ergo LAB man-machine environment synchronization platform. Each subject was required to observe the

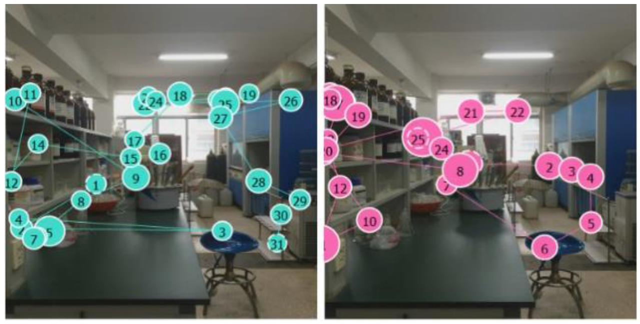

FIGURE 1. Fixation point trajectory of the subjects.

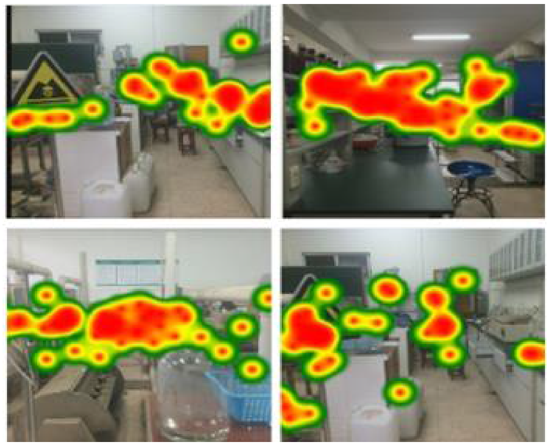

FIGURE 2. Heat point distribution.

laboratory pictures without informing the purpose of the experiment. They were asked to focus 3-5 seconds intently on what they identified and considered a source of hazard. During the observing process of the experiment, the subjects' eye movement parameters were recorded and saved by eye tracker.

III. RESULTS AND DISCUSSION

A. FIXATION POINT TRAJECTORY CONTRAST ANALYSIS

Through the eye movement tracking experiment module, the fixation point trajectories of the subjects were obtained, as shown in figure 1. According to the fixation point trajectories, more than 90% of the subjects' eye gaze paths are from center to the surrounding. A small number of subjects' eye gaze paths are from left to the right in the laboratory images. More than 90% of the subjects observed the five regions in the order of equipment area (B), container area (C), wireway area (D), medicine area (E), sign area (A).

B. REGIONAL FOCUS DIFFERENCE ANALYSIS

Export subjects' hot spot maps and focus level peaks in observing laboratory images, as shown in figure 2. And their focus degree was divided into three classes. The red part in the hot spot map represents the fixation and gaze center part of the subject. It means the subject pay the highest attention on it, defined the red part as key focus (class I). The yellow

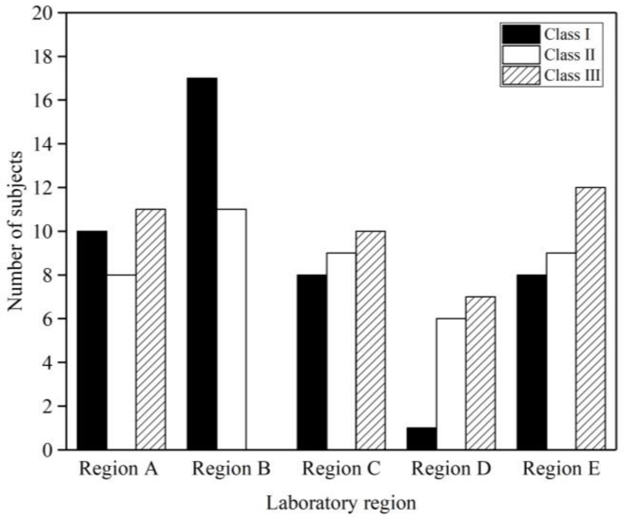

FIGURE 3. Distribution of subjects' focus levels among five laboratory regions.

TABLE 2. The proportion of the subjects' focus level on five laboratory regions.

Proportion of focus degree	*A* (medicine area)	*B* (equipment area)	*C* (container area)	*D* (wireway area)	*E* (sign area)
Ratio of class I	34.48%	56.67%	29.63%	7.14%	27.59%
Ratio of class II	27.59%	43.44%	33.33%	42.86%	31.03%
Ratio of class III	37.93%	0%	37.04%	50.00%	41.38%
Ratio of total subjects	96.67%	100%	90.00%	46.67%	96.67%

part represents the areas the subjects glimpsed near the gaze center defined the yellow part as less focus (class II); The green part represents the edge of the subject's line of sight defined the green part as scarcely focus (class III).

The distribution of subjects' focus levels in each area is shown in Figure 3. Region B (equipment area) obviously attracted the greatest attention, and region D (wireway area) attracted the least attention. The other three regions showed similar attention patterns.

To better visualize the results, the proportion of subjects' focus levels and the ratio of the number of subjects who focused on each region to the total subjects was calculated, as shown in Table 2.

Using region A as an example, 96.67% of the total subjects paid attention to region A. Additionally, 34.49% of the total subjects had a key focus on region A; 27.59% of the total subjects exhibited less focus on region A; and 56.67% of the total subjects had scarcely focus on region A.

Region B attracted the most attention from the subjects, and the rate reached 100%. Therefore, all subjects paid attention to region B; 56.67% of the total subjects exhibited a key focus on region B. Region D attracted the least attention, with only 46.67% of the total subjects paying attention to this region. Additionally, 7.14% of the total subjects exhibited a key focus on region D.

The weighting and quantifying method was adopted to intuitively determine how much attention that the subjects paid to each region. Three, two and one points were assigned to the class I, class II and class III focus degrees, respectively, and then the focus degree score, t, was obtained ($t_I = 3$, $t_{II} = 2$, $t_{III} = 1$). The number of subjects who paid attention to each region was multiplied by the corresponding focus degree score, t, and the focus score, T, of each region was obtained. For example, the focus score, T, of region A can be calculated according to Equation (1).

$$T_A = N_{AI}^* t_I + N_{AII}^* t_{II} + N_{AIII}^* t_{III} = 10^*3+8^*2+11^*1 = 57 \quad (1)$$

where T_A indicates the focus score T of region A; N_{AI} indicates the number of the subject who have the key focus (class I) on region A; t_I indicates the class I focus degree, and so forth.

Using this method, the scores for each region were calculated using Equation (2).

$$T_A = 57; \quad T_B = 77; \; T_C = 52; \; T_D = 22; \; T_E = 52 \quad (2)$$

According to the results, region B exhibited the highest score of 77, and region D exhibited the lowest score of 52. Region B is the equipment area, and electrical equipment occupies a large part of the laboratory space. These devices are usually placed in plain sight; therefore, the subjects paid more attention to this region. Region D is the wireway area, and objects in this area usually do not occupy a large amount of space. They are often placed in inconspicuous places, such as corners and edges of walls, which are not easily noticed. Therefore, the subjects paid little attention to this region. The other three regions showed similar scores.

C. SPECIALTY DIFFERENCE ANALYSIS

The degree of focus of the subjects on regions A to E was determined while considering the differences in the subjects' professional knowledge. The results are shown in Figure 4.

No significant difference was observed between subjects who were specialized or not specialized in safety in their attention to different laboratory areas. A survey of the subjects was conducted to determine why this occurred. We found that this phenomenon could be explained by the experimental operation experience of subjects in the laboratory. The subjects were all junior students with experience in conducting experimental operations during their university experience, and they all had a certain understanding and primary knowledge of hazard identification in university laboratories. Therefore, they all had similar observation patterns.

D. KEY ITEMS ANALYSIS

The key items included safety management regulations, gas cylinders, warning signs and electrical sockets. The reasons why these areas were included are as follows:

1. Safety management regulations are important factors to ensure the normal operation of laboratory equipment,

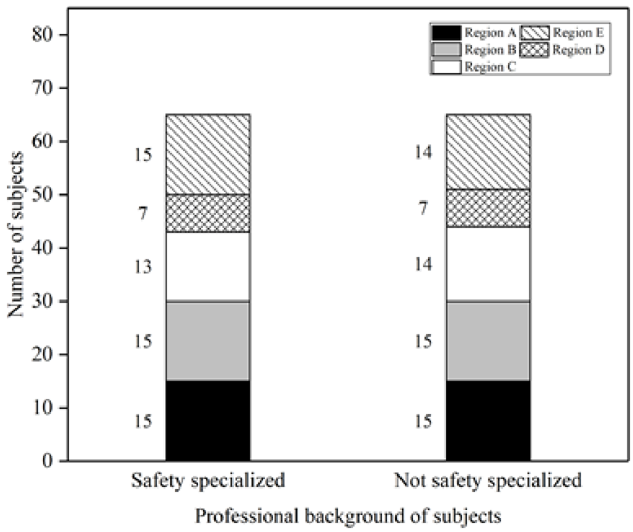

FIGURE 4. Distribution of subjects' interest in areas with regard to the laboratory focus area based on major differences.

the personal safety of relevant operators and the safety of the whole laboratory. Operators must consider these regulations when carrying out experimental operations.

2. Improper management and use of laboratory gas cylinders is very likely to lead to major accidents (such as poisoning, fire and explosion). Even non-toxic gases such as argon, nitrogen and carbon dioxide are difficult to detect because they are odorless, and they are likely to cause suffocation or even death.

3. A laboratory safety warning board plays a role in effectively avoiding or reducing accidents.

4. Aging of electrical circuits is a severe hidden hazard in the laboratory. This may cause electrical appliances to burn out, resulting in a fire or electrical shock. Therefore, electricity safety in the laboratory is also a key issue that cannot be ignored.

Because these four items play a vital role in laboratory safety, they were isolated and classified as key analysis objects. According to the statistical analysis of the experimental results, the numbers of subjects who exhibited all levels of focus on the four key items are shown in Figure 5.

Figure 5 shows that among the four items, the subjects paid the most attention to warning signs, followed by gas cylinders and safety management regulations. The subjects paid the least attention to electrical sockets; no subject had a key focus (class I) on this item.

In order to intuitively reflect the differences between the levels of focus on each key object, the proportion of each subject's focus level on each key item was calculated. Using safety management regulations for example, the proportion of subjects who were concerned about safety management regulations was 46.67%. Among them, 14.29% exhibited a key focus (class I), 28.57% exhibited less focus (class II), and 57.14% exhibited little focus (class III). The algorithm described above was used to determine the results for the other three key items, and the results are shown in Table 3.

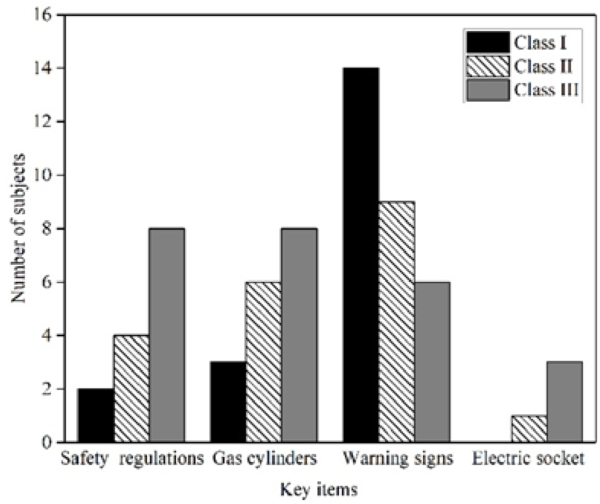

FIGURE 5. Distribution of subject focus levels on the key laboratory items.

TABLE 3. The proportion of subjects that focused on each laboratory area according to degree of focus.

Proportion of focus degree	Safety management regulations	Gas cylinders	Warning signs	Electrical sockets
Ratio of class I	14.29%	17.65%	48.28%	0.00%
Ratio of class II	28.75%	35.29%	31.03%	33.33%
Ratio of class III	57.14%	47.06%	20.69%	66.67%
Ratio of total subjects	46.67%	56.67%	96.67%	10.00%

Table 3 shows that the subjects paid a high degree of attention to the warning signs, with an attention rate of 96.67% for the total subjects. Among them, 48.28% exhibited a key focus (class I) on this area. However, only 10.00% of the total subjects paid attention to electrical sockets, and no subject exhibited a key focus (class I) on this area.

Thus, it can be inferred that electricity safety is one of the most neglected safety problems in university laboratories. Compared with chemical safety, biosafety and radiation safety, electricity safety is easily underestimated or ignored because of the large number of users. Therefore, people will neglect safety precautions in this area. When the number of apparatuses and amount of equipment in the laboratory are increased, the interface of the plug board is increased, and the power distribution will become insufficient. Alternatively, if the wire is older or disorganized, accidents such as electric shock and fire can easily occur.

IV. COUNTERMEASURES AND SUGGESTIONS

A. PARTITION AND COLOR DESIGN

According to the fixation point analysis, most subjects' observation patterns in the university laboratory followed a path from the center to the surroundings. Additionally, the distribution of different functional regions in the laboratory had a certain influence on the subject's observation pattern of the laboratory. Therefore, in designing university laboratories, not only the functionality of the laboratory but also the rationality of the layout should be considered. For example, regions where a source of danger exists, such as areas where hazardous chemical storage cabinets or large instruments and equipment located, should be placed in the visual center in the laboratory. To ensure the personal safety of operators and others when using hazardous chemicals or those in contact with laboratory facilities and equipment, especially during start-up and operation, a safe operation area should be defined. In addition, when installing devices, the distance between the devices should be sufficient, and a reasonable distance should be left between the device and the wall.

The color design of the laboratory can be based on the different degrees of focus of subjects on various regions in the laboratory. For instance, inconspicuous items that need to be the focus of attention should be marked with a distinct color. The regions of the laboratory can be separated by different colors according to the international safe color division principle as follows: (1) a red line represents a region where access should be limited and where fire-fighting equipment is located; (2) a yellow line represents a region where a hazard source exits and special attention is required; (3) a blue line represents a region where instruction information such as laboratory safety management regulations is located; (4) a green line is used to indicate the operation area and channel.

B. ENSURANCE OF ELECTRICAL SAFETY

In recent years, various types of laboratory accidents caused by improper use of electricity have continuously been reported. The results of this experiment, showing that operators pay little attention to electrical safety, could explain this phenomenon. Therefore, electrical safety is an important safety issue for laboratories that cannot be ignored. Additionally, laboratory managers should pay increased attention to the use of electricity in laboratories.

When the laboratory is modified or expanded and a new power system is added, the old unused lines and equipment should be dismantled immediately. Overload operation of laboratory power should be strictly prohibited, and various switches, sockets, plugs in the laboratory power lines, distribution boxes, leakage protectors and line systems should be kept in good condition. Additionally, universities should also increase the publicity and education regarding laboratory safety. Improving the electrical safety awareness of operators is the key to laboratory electrical safety management. After all, prevention is the best safeguard.

V. CONCLUSION

Eye movement tracking technology can demonstrate a subject's observation pattern in a university laboratory and record the characteristics of eye movement parameters. It can also reflect how subjects perceive of laboratory hazards and provide objective and authentic data support for laboratory safety management.

By analyzing the differences in subjects' hazard identification abilities in various university laboratory areas, it can be concluded that the equipment area is most likely to be the focus of subjects, while the wireway area is most likely to be neglected. To examine this phenomenon, four typical objects including safety management regulations, gas cylinders, warning signs and electrical sockets in five areas were tested and analyzed separately as key analysis items. The results showed that the subjects tended to pay more attention to warning signs because of their bright colors. Electrical sockets were the most overlooked hazard source among the four key items because they are common and widely used in daily life. Based on these differences, the laboratory layout, color design, device distribution and electricity safety awareness of operators can be considered in laboratory safety management.

This study considered different laboratory regions and the subject's professional background. However, because of individual diversity, the sample size needs to be expanded, and the impacts of physiological parameters of the subjects and the test environment should be more comprehensively considered. Future research could examine whether such measures continue to be valuable indicators when different samples, laboratories and testing environments are used.

REFERENCES

[1] H. F. Gou and J. X. Lu, "Discussion on the major hazardous source and safety monitoring system," *Ind. Saf. Environ. Protection*, vol. 35, no. 3, pp. 48–50, Mar 2009.

[2] 2 M. Snakard, "Challenges in applying process safety management at university laboratories," *J. Loss Prevention Process Industries*, vol. 49, pp. 209–214, Sep. 2017.

[3] D. J. Leggett, "Lab-HIRA: Hazard identification and risk analysis for the chemical research laboratory. Part 2. Risk analysis of laboratory operations," *J. Chem. Health Saf.*, vol. 19, no. 5, pp. 25–36, Sep. 2012.

[4] D. L. Braham, A. L. Richardson, and I. S. Malik, "Application of the WHO surgical safety checklist outside the operating Theatre: Medicine can learn from surgery," *Clin Med*, vol. 14, no. 5, pp. 468–474, Oct. 2014.

[5] S.-Q. Zhao, C.-L. Xiang, L. Su, Z.-Y. Jiang, and C.-J. Liao, "Study on the eye movement characteristics of fire hazard identification in university laboratories," *Procedia Eng.*, vol. 211, pp. 433–440, 2018.

[6] H.-C. Liu, M.-L. Lai, and H.-H. Chuang, "Using eye-tracking technology to investigate the redundant effect of multimedia Web pages on viewers–cognitive processes," *Comput. Hum. Behav.*, vol. 27, no. 6, pp. 2410–2417, Nov. 2011.

[7] M. Terenzi, F. D. Nocera, and F. F. Action, "Not only semantics, underlies expected location for interface elements," in *Proc. 4th Italian Symp. Hum. Comput. Interact.*, Roma, Italy, Sep. 2005, pp. 23–27.

[8] S. A. Balk, K. S. Moore, J. E. Steele, W. J. Spearman, and A. T. Duchowski, "Mobile phone use in a driving simulation task: Differences in eye movements," *J. Vis.*, vol. 6, no. 6, p. 872, Mar. 2010.

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