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A Study of the Hand Operating Thresholds during the Usage of an Electric Steam Iron by College Students

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ABSTRACT
Among various types of home appliances, an electric steam iron has a higher risk since it needs to operate under a condition with a higher range of temperature. In this study, a group of college students were invited to operate an electric iron during the experiment in order to investigate the correlation between an operator's hand and the possible contact with the iron soleplate during usage. The purpose of this study was to determine the hand portions which could easily get burned and the portions of the iron soleplate which tend to cause injuries. The results of this study indicated that the hand portions which could easily touch the soleplate are the right-hand side of the thumb and the forefinger. On the other hand, the portions on the soleplate which tend to cause burns are on the left-hand side of the iron, especially the sharper and upper half. The results serve as a good reference for follow-up designers on an iron design based on the safety consideration.

Keywords: ergonomics, operating threshold, product security, usability engineering

INTRODUCTION

During the activities and tasks of daily living, it seems to be unavoidable for people to carelessly get hurt due to their negligence. The purpose of ergonomics is to investigate the capability, behavior, limitation, and demands of humans so that these types of information could be utilized to create designs that are suitable for human usage. It can further reduce the probability of incidents and enhance the work efficiency at the same time. Among various types of home appliances, some of them usually operate at a higher range of temperature and these include a water boiler, oven, electric heater, steam iron, etc. Among them, an iron needs to operate at higher temperature and it has a higher risk level. When a person is operating an iron, his/her hands are in direct contact with it and therefore the injuries during iron operation typically occur on hands. Due to different functional requirements, different portions of hand skin have different degrees of pain tolerance such as the difference between the palm and the back of hand. The portion of an iron that could easily cause injuries is on its soleplate. Due to this consideration, the main objective of this study is to investigate the conditions of the contact between hand and iron soleplate during iron usage. It is expected to verify the hand portions that could easily get burned and the soleplate portions that could easily cause injuries. The results serve as a good reference for designers in the future when carrying out iron designs based on the safety consideration.

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State of the literature

- Via the configuration of a typical task, the discount usability engineering approach can be used to determine the problems of individual usability. This approach can satisfy professional user for their problems and demonstrate a user's real tasks from the effectiveness in ecology by recommending functional developments and the description of characteristics.
- A simple approach was proposed for carrying out the usability evaluation model. It was used to determine the range of evaluating the interface of home appliances and to measure the usability.
- The theories of space allocation were applied to the measurement of human hands so that the optimal layout for operation can be obtained.

Contribution of this paper to the literature

- An approach for assessing the operating efficiency of an interface is proposed.
- The comfortable and accessible areas of an interface can be obtained by this approach based on palm dimensions.

LITERATURE REVIEW

Ergonomics

The term *ergonomics* came from the western world and it was usually called *human engineering* in the past. This term was often confused by people as a subject that studies humans or human bodies and thus was not favored by professionals and had been gradually declined. There was subsequently another term *human factors engineering* or simply *human factors*, which was generally called ergonomics. Its implication is to investigate the physical and psychological human factors that should be considered during an engineering design.

The definition of ergonomics by Sanders & McCormick (1993) is as follows. The objective of ergonomics is to discover and apply various types of knowledge in relation to human behaviors, capability, limitations, and other characteristics to the design of a tool, machine, system, operation, or working environment. The ultimate purpose is to make human usage more productive, safe, comfortable, and effective. More specifically, ergonomics is to pursue two main goals as follows. The first goal is to carry out ergonomic designs for human usage. The second goal is to apply ergonomics in pursuit of the optimization of working and living conditions.

Ergonomics is a subject that integrates several other subjects. Its fundamental research scope generally includes several topics as follows.

1. Human body measurement data: The measurement data of various features of a human body. This includes dimensions of various portions of a human body, range of movements, and other measures that are relevant to physical and psychological capabilities.
2. Human characteristics: This topic includes feelings such as vision, hearing, smell, etc., information input/output, human fitness activities such as physical functions, workload, biomechatronics, muscular strength, endurance, etc.
3. Human-machine interface design problems: This topic include display devices, control device design, hand tool design, working space and layout, and manual material handling.
4. Environmental factors: This topic includes the description and investigation of physical factors such as workplace lighting, daylighting, noise, temperature and humidity conditions, and vibration.

The emphases of the discussions in this study include the movement range of hands during operation, product component layout, and injuries during usage.

USABILITY ENGINEERING

Since the usability engineering concept was first proposed in 1990s, it has been widely discussed and applied to various aspects such as interface, product, and system designs. Nielsen (1993) proposed that usability testing is a technique used to evaluate a product by testing it with representative users. In the test, the users will try to complete typical tasks while observers watch, listen and takes notes. Heuristic-based design and evaluation are rules of thumb based on design principles. They can be used to guide the design of a usable GI product or to help assess or evaluate a working prototype.

According to the definition in the DIS 9241-11 standard by International Standards Organization (ISO), usability deals with the goal, efficiency, and degree of satisfaction that a user can achieve under a specific environment. It states that to determine usability, user performance and satisfaction must be measured. Usability measures are important, considering the complexity of interactions among the user, the task characteristics, and other elements within the context of use. A product can have significantly different levels of usability when used in different contexts. The standard also states that measures of user performance and satisfaction can provide a basis for comparing the relative usability of products having different technical characteristics used in the same context (ISO 9241, part 11, 1998).

Bevan et al. (1991) proposed that usability exists within the interactions between a user and products and systems. Moreover, usability can be measured by the performance, degree of satisfaction, and degree of acceptance. For a product, usability is a user's point of view toward the product's quality. Therefore, when there is any change in a product, system, user, work, or environment, the usability is affected. From the design point of view, the features of usability engineering are related to efficiency, performance, safety, comfort, and degree of satisfaction. The factors to be considered include "Who the user is?", "What the task is?", and "Under what environment is it used?" These factors frame the entire usability engineering. Nielsen (1993) proposed that usability is to describe the quality of a product or a system and it is more objective and equitable. He also proposed that usability evaluation of a system or a user interface is not of single dimension but is composed of five indices as follows.

1. Learn ability: The degree of easiness for a user to learn and use an interface or system.
2. Efficiency of use: The effectiveness for a user to use an interface or system effectively so as to ensure the usage efficiency of an interface or system can be enhanced.
3. Memorability: The degree of easiness for a user to memorize the way of using an interface or a system without forgetting how to use it after a while without using it.
4. Few and no catastrophic errors: The lower error rate for an interface or system so that the usage of an interface or system won't be affected by a user's wrong way of using it.
5. Subjective satisfaction: The higher degree of subjective satisfaction when a user is using an interface or system so that a product's degree of usage is enhanced.

Meanwhile, Nielsen also proposed four stages for the procedure of implementing the discount usability engineering into product design processes. These four stages for the evaluation procedure are as follows.

1. Develop appropriate scenarios,
2. Select appropriate tasks,
3. Perform user/work observations,
4. Conduct a heuristic evaluation.

The contents include the observation of a user's subjective responses, objective responses, and the way of using a product so as to find any problem and propose recommendations. The discount usability engineering approach can be used to determine the individual usage problems via the configuration of typical tasks. It can satisfy professional user problems and effectively present a user's real task from the ecological point of view so as to recommend functional developments and characteristic descriptions.

Besides, usability tests represent an important and widely used tool in product development (Jordan, 1998). Their aim is to identify design shortcomings throughout the product development process by evaluating the product or a prototype of it with prospective or real users and realistic tasks (Gould and Lewis, 1985). Typical measures collected in usability tests are effectiveness (extent to which typical user tasks are successfully completed) and efficiency of task completion (amount of resources that have to be spent to reach a task goal) as well as the satisfaction a user experiences by using the product. Newer approaches in usability evaluation have enlarged the concept of usability and consider the whole user experience in product evaluation (Marcus, 2003; Norman, 2004). Sonderegger and Sauer (2013) proposed five typical user tasks in the context of coffee machine usage, measuring performance, perceived usability, and emotion.

The studies by Kwahk & Han (2002), Lee et al. (2006), Lee et al. (2006), Heo et al. (2009), Jin & Ji (2010) also proposed quantitative approaches for carrying out the principles of usability evaluation respectively. They also recommended introducing the usability risk level evaluation during the earlier stage of conceptual designs since a design at the earlier stage will affect the usability interface. From the aspect of product designs, Chou (2016), Hsiao et al. (2017), and Ko et al. (2017) proposed decomposing and analyzing a product by perceptions and practical operations in order to determine the optimal solution.

Hand Structure

The external form of a hand can be classified into four portions which include wrist, palm, back of hand, and fingers. Each hand has five fingers, which are respectively the thumb, forefinger, middle finger, ring finger, and pinky finger. A finger is consisted of portions such as the finger pulp, fingertip, and the nail. The thumb side where the upper arm radius is located is called the radial side or the outer side. The pinky finger side where the upper arm ulna is located is called the ulnar side or the inner side. The wrist connects the forearm to the wrist. The inner side of the portion where the wrist connects to fingers is called palm and the outer side is called the back of hand. The central recess of the palm is called the center of the palm. The muscles on the radial side and the ulnar side are more developed and they present a bulge in the shape of a fish belly. These muscles are called thenar muscle and hypothenar muscle respectively.

Due to different functional requirements on the hand skin, there are differences between the skin on the palm and that on the back of hand. The skins on the palm and the finger sides are rougher with a thicker stratum corneum. There is a thicker fat pad within the subcutaneous so that the skin is not damaged when in touch with any rough items. There are vertical fiber intervals under the hand skin so that the skin connects to deeper tissues such as finger bones and epitenon. This structure avoids much sliding of the skin and therefore the elasticity of the palm-side skin is lower. On the contrary, the skins on the back of hand and finger back are thin, soft, and elastic. The hypoderm is loose with a larger degree of sliding.

The emphasis of this study is on the contact area between hands and an iron along with the corresponding risks of getting burned when operating an iron.

Average Skin Temperature and Feeling Hot or Cold

According to the *Development of Workplace Hazard Evaluation in Extreme Temperature* published by Institute of Labor, Occupational Safety and Health, Ministry of Labor, Ministry of Labor, Executive Yuan, Taiwan, in 2008, when the skin is exposed to a temperature that is higher than 45°C, the tissues get damaged quickly. Since an iron remains at a temperature higher than 45°C during the ironing process, the user can get injured easily if he/she touch the iron soleplate carelessly. The average temperature and the corresponding feeling of hot or cold can be summarized into **Table 1** according to the study by Gagge & Nishi (1977).

EXPERIMENTAL APPROACH

College students were selected as the research subjects in this study. This is due to the fact that there are currently about 100,000 college students in Taiwan and approximately 50,000 of them are renting private accommodations outside the school. Therefore, there is a great chance for them to use personal home appliances and college students were selected for the investigation. Among various types of home appliances, irons are among the most frequently used home appliances for college students. Therefore, the case study was carried out on irons for further investigation.

Table 1. Average skin temperature and the corresponding feeling of hot or cold

Average skin temperature (°C)	Skin feeling
45	Fast injury of tissues
41~43	Threshold of burning pain
39~41	Threshold of instant pain
35~39	Feeling hot on the skin
35~37	Beginning of warm or hot feeling
33~34	Feeling of moderate temperature and comfortable during rest
32~33	Feeling of moderate temperature when the metabolism rate is 2~4 MET
30~32	Feeling of moderate temperature when the metabolism rate is 3~6 MET
30~36	Skin temperature is roughly equal to the operating temperature ($t_{sk} \fallingdotseq t_0$) and is not related to metabolic heat
29~31	Feeling uncomfortable and cold without any activity
25 (Local)	Feeling numb on the skin
20 (Hand)	Uncomfortable and cold
15 (Hand)	Very uncomfortable and cold
5 (Hand)	Cold and cannot bear the pain anymore (may lose skin sensation)

Table 2. Fundamental process of operating an iron

Step #	Operating behavior	Relevant component
Step 1	Shut off the steam	Thermostat
Step 2	Fill water in	Fill opening
Step 3	Set temperature/ material	Status button
Step 4	Lift the iron up	Handle/Lift support
Step 5	Plug in	Power plug
Step 6	Wait while temperature is increasing	Status indicator
Step 7	Ironing	Handle/ steam soleplate /steam button
Step 8	Wait while the iron cools	Status indicator
Step 9	Release water	Water outlet port

Table 3. Descriptions of ironing steps

Step Number	Operation action
Step 1	Ironing collars
Put the iron down and lift it up	
Step 2	Ironing sleeves
Put the iron down and lift it up	
Step 3	Ironing around buttons

The experiments in this study were carried out in three portions as follows.

1. Analysis of the procedures of operating an iron
2. Measurement of subjects' palm sizes for a group of college students
3. Practical operations of experiments by a group of college student

Analysis of The Procedures of Operating an Iron

The first step is to analyze the procedures of operating an iron. The complete process of the typical way of operating an iron is summarized in **Table 2** as follows. Among these steps, the ironing process in Step 7 is most likely to cause injuries since the user might easily and accidentally touch the soleplate. Based on this, we focused on this ironing process and further classified this process into ironing different portions of clothes including ironing the collars, ironing the sleeves, and ironing around the buttons. During each of the steps, we asked the subjects to put the iron down and lift it up again as described in **Table 3**.

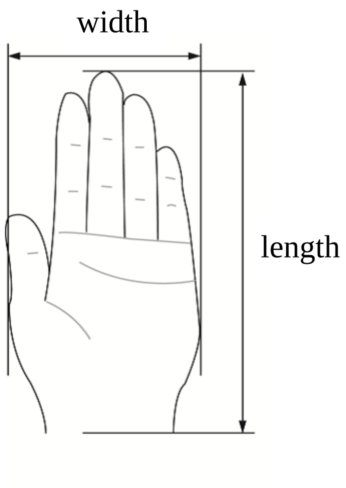

Figure 1. Dimensions of a left palm for measurement

Table 4. Summary of the data of all subjects

Subject #	Gender	Age	Frequency-of-use (Month/once)	Palm length (cm)	Palm width (cm)
1	Female	24	6	9	16.5
2	Female	25	12	9	17
3	Male	25	1	10.5	18.5
4	Male	24	12	11.5	19
5	Female	32	6	8.5	17.1
6	Female	23	1	8.8	17.9
7	Female	25	12	8.3	17.2
8	Female	23	3	9.4	19.5

Data of Subjects and Measurements of Their Palm Sizes

There are total of 8 subjects in this experiment. Among them, there are 2 males and 8 females and they are in the age of 23~32 years old. All of them have the experience of using an iron. During the process of using an iron, a user usually grasps the iron by his/her right hand which is less likely to touch the iron's soleplate. Therefore, the experiment in this study stressed at the investigation on their left hands. At the beginning of the experiment, we measured the size of each subject's left palm in the way as shown in **Figure 1**. A summary of the detailed data of the subjects are as shown in **Table 4**.

Practical Operations of Experiments by The Subjects

The main purpose of this experiment is to understand the condition of the contact between a user's hand and the iron soleplate when he/she is using an iron. Via this experiment, we can understand which portion on the hand can easily get burned and the portion which tends to be in contact with the iron soleplate. The iron model for experiment is an elongated steam iron EUPA TSK-711LC. This model was selected for experiments since it is easy-to-use, inexpensive, and practical for a college student to use in his/her renting accommodation when studying in a place other than his/her home. In order to reduce the number of research variables during the experiments, the same test specimen was used in this study.

The experiment was carried out in a way that each of the subjects was asked to go through the ironing steps including ironing collars, ironing sleeves, and ironing around buttons as shown in **Table 3**. We also observed the subjects' operating behaviors so as to analyze and conclude the condition of the contact between a subject's

Figure 2. The first camcorder to record the experiment from the front

Figure 3. The first camcorder to record the experiment from the left

Figure 4. The first camcorder to record the experiment from the right

hand and the iron soleplate when he/she was performing the steps with the iron. To prevent the subjects from really getting burned, they carried out the experiment by keeping the iron unplugged. However, to ensure no loss during the observation of this experiment, we used three camcorders to record the experiment from the front, left, and right of each subject as shown in **Figures 2~4**. This allows us to repeatedly observe and analyze the operation conditions of each subject.

EXPERIMENTAL RESULTS AND ANALYSIS

We observed the ironing operation process of each subject and carried out analysis and investigation on the portion of each subject's left hand in contact with the iron soleplate and the relevant distances. The observation results of these eight subjects are summarized into figures, in which different colors indicate different contact distances and risk levels. Risk Level 1 is in red and it indicates the distance between hand and soleplate is in the range of 0~1 cm. Risk Level 2 is in orange and it indicates the distance between hand and soleplate is in the range of 1~2 cm. Risk Level 3 is in yellow and it indicates the distance between hand and soleplate is in the range of 2~3 cm. Risk Level 4 is in green and it indicates the distance between hand and soleplate is in the range of 3~4 cm. These risk levels are summarized in **Table 5**. After all of experiments finished, the contact condition between each subject's hand and iron soleplate is summarized in **Figures 5~12**.

Table 5. Assessment table of the contact between a subject's hand and the iron soleplate

Range of distance (in cm)	0-1	1-2	2-3	3-4
Risk level	1	2	3	4
Level color				

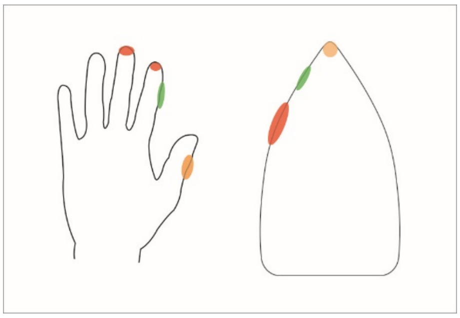

Figure 5. Portions of contact between Subject #1's hand and the iron soleplate

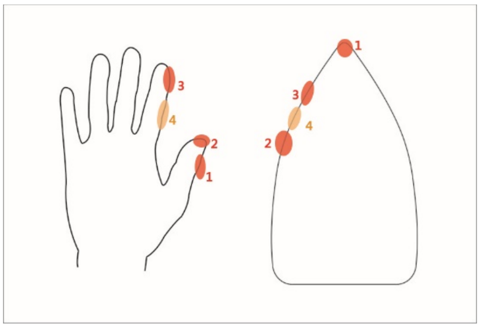

Figure 6. Portions of contact between Subject #2's hand and the iron soleplate

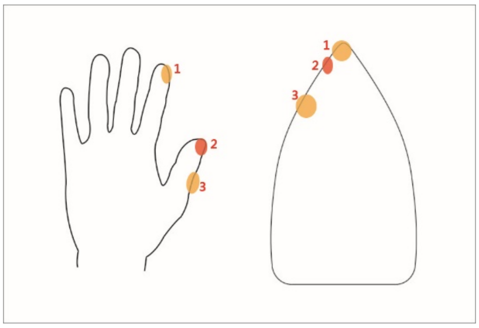

Figure 7. Portions of contact between Subject #3's hand and the iron soleplate

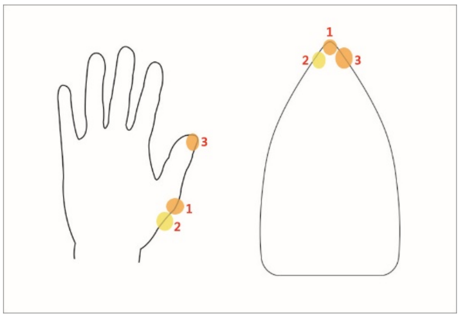

Figure 8. Portions of contact between Subject #4's hand and the iron soleplate

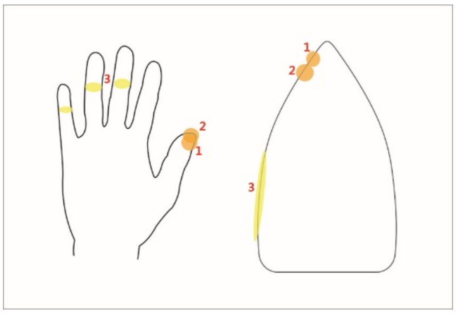

Figure 9. Portions of contact between Subject #5's hand and the iron soleplate

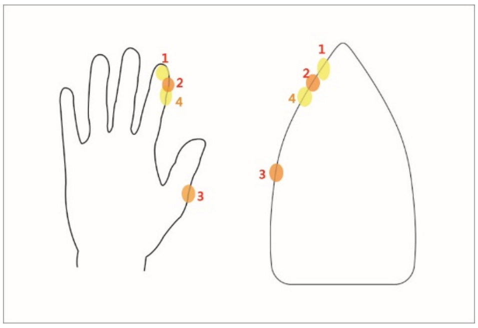

Figure 10. Portions of contact between Subject #6's hand and the iron soleplate

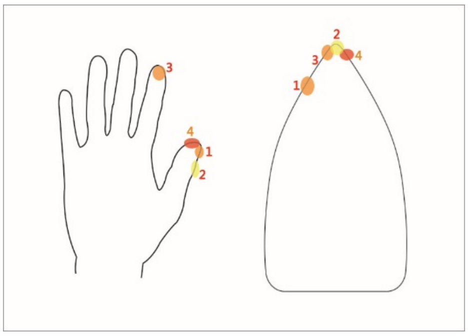

Figure 11. Portions of contact between Subject #7's hand and the iron soleplate

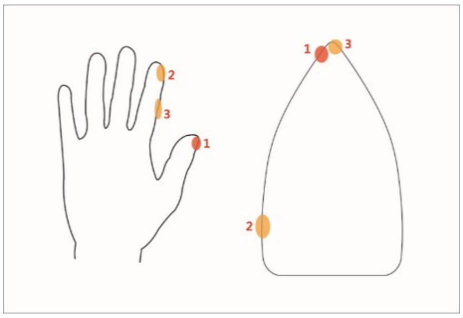

Figure 12. Portions of contact between Subject #8's hand and the iron soleplate

The conditions of the contact between the hands and the iron soleplate for each research subject were recorded and reviewed. The hand portions that tend to touch the iron soleplate during the ironing process for all of the subjects are summarized in **Figure 13**, in which a darker color indicates a higher frequency of contact with the iron soleplate. On the other hand, the portions of the iron soleplate that can easily get in touch with the iron soleplate are shown in **Figure 14**, in which a darker color indicates a higher frequency of contact.

Figure 13. Probability distribution for contacts with the iron soleplate on the hand

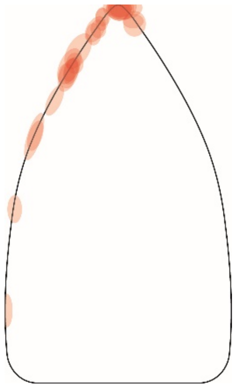

Figure 14. Probability distribution for contacts with the hand on the iron soleplate

CONCLUSIONS AND SUGGESTION

The results of the experiments indicated that the portions on the subjects' hands with the highest probability of contact with the iron soleplate are the right-hand sides of the thumb and the forefinger. The portions on the iron soleplate with the highest probability of contact with the hand are mainly on the left-hand side and especially the upper-left tip portion. Therefore, any follow-up research on the safety considerations for an iron design is advised to aim at these two portions for improvement or further protective measures so as to enhance the safety of an iron and reduce the probability for a user to get burned during operations.

For follow-up studies, it is recommended to carry out the analysis of the modification of interface layouts for typical tasks of operations in order to determine the optimal solution to the interface layout of an iron. No further research was carried out in this study on the iron's own material. Using a lightweight material for an iron can reduce the burden on a user's muscles. Therefore, the burden on muscles and the lightweight consideration should serve as the development emphasis for follow-up studies.

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