Research on the Distribution of Attention in the Course of Maintenance Training

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***Abstract*—This paper explores the attention distribution of different users in the process of maintenance training, based on the theoretical study and the eye tracking technology. Contrast design is used in the experiment, 12 participants complete a task on a virtual platform, and experiment analysis integrates application of eye movement measurements and subjective evaluation. Experimental results show that users with different experiences has different performance, the results are basically the same user subjective feelings. This paper provides a good basis and guidance for maintenance training.**

***Index Terms*—Maintenance Training; Attention Allocation; Eye Tracking; Human-Computer Interaction**

I. INTRODUCTION

With the development of advanced science and technology, product quantity of defense, automotive and other industries are increasing fast, so as the product technical content. These products have comprehensive function and complex structure; it puts forward higher requirements on maintenance personnel training. A traditional use of actual product for repair training can not meet the requirements [1], so virtual maintenance training, a use of virtual reality technology for maintenance training methods becomes an effective solution.

Virtual maintenance training provides a virtual training environment to transfer users training knowledge, as well as the position of the structure of the equipment, spare parts and maintenance actions and maintenance process, etc. Most of the maintenance content can be transferred by virtual training. Virtual maintenance training can realize all kinds of experience, especially experience not easy to get in reality. For effective use of the function technical characteristics of virtual maintenance training, the training process should be designed effectively, selecting the best way to apply. Virtual maintenance training system is divided into three categories [2]: non-immersive virtual maintenance training system, immersive virtual maintenance training system and other types. Non-immersive virtual maintenance training system are not total Immersion, generally the computer screen is a window for user to observe the virtual world, using a variety of input devices such as mouse, trackball, torque ball implementation and training environment interaction. Immersive virtual maintenance training system uses typical immersive virtual reality peripheral equipment, such as the HMD, data glove, operate handle and so on, training personnel are trained in immersive virtual environment. Typical virtual maintenance training system for other types is enhanced training system. Its characteristic is put the enhanced virtual reality technology as the core, put various auxiliary additional information to the physical through virtual reality peripheral equipment. At present, the last kind of training system is gradually taken seriously.

Virtual maintenance is an important application field of virtual reality technology. International study on it began at the end of last century. The American academy of engineering listed the maintainability analysis and maintenance training applied virtual reality technology as a cutting-edge research in the field of engineering in 1996 frontier seminar. Many scientific research units and colleges and universities are also carried out for the application of virtual reality technology in maintenance training research in China. But the research mainly concentrated in the technical level, less theoretical research [3]. The first Air Force Academy made a preliminary discussion on the application of maintenance technology in training based on the composition and current situation of the development of the virtual maintenance system. Information engineering university explored a new method for external equipment maintenance training under the environment of multimedia computer, constructing a comprehensive maintenance training system with a software simulation core.

Attention is an important psychological adjustment mechanism during the information process; it is capable of allocating limited information processing resources, which provide perception with the ability to choose [4]. By now, there are different degrees of studies on attention

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allocation modeling. Senders et al, who established the first instrument to monitor the behavior of a quantitative model, using the concept of visual information bandwidth to explain the behavior of operating personnel glance [5]. Itti et al put up with an attention model based on the information salience, which integrated brightness, color, orientation and other visual features in information [6]. Wickens understood the factors affecting concentration distribution as information dominance, efforts, and expected value, and established the SEEV model by first weighting method [7]. Nobuyuki et al gave out the attention allocation model of car driver, explained the relationship between the psychological and mental activity and attention mechanisms by fuzzy control model [8]. Wu Xu et al, from China Beijing University of Aeronautics and Astronautics, started from two paths of information, put forward an attention allocation prediction model based on information important degree, the probability of occurrence, dominant and effort [9]. However, these models all predict allocation of attention based on traits of interface elements and the user's subjective expectations. In fact, users using the interfaces are in certain situations, operating with a certain purpose, attention is constantly shift with the task [10], attention resources should be dynamic allocated combined in different scenarios.

This paper explores the attention distribution of different users in the process of maintenance training, based on the theoretical study and the eye tracking technology. Contrast design is used in the experiment, 12 participants complete one task on a virtual platform, and experiment analysis integrates application of eye movement measurements and subjective evaluation. Experimental results show that users with different experiences has different performance, the results are basically the same user subjective feelings. This paper provides a good basis and guidance for maintenance training.

II. THEORETICAL STUDY

People's attention and attention allocation model plays an important role to understand human cognitive characteristics, carry out a visual interface to optimize the layout and user-friendly designed visual coding. When there are multiple message appears on the operator interface required to identify and make decisions, human information processing system allocate attention on each message according to the degree of importance of the information, so that it establishes the intrinsic link between information importance and attention allocation. Information stimulation time, indicated manner, color and location will also affect the distribution of attention, they will be considered as information importance factors.

Attention model created by Kleinman assumes that people's brain can process information and intelligence parallel, and assumes that human has limited capacity for processing information [11], thus the total number of channels N is fixed, attention allocation mathematical expression is:

$$\mathrm{f}_i = \frac{N_i}{N} \tag{1}$$

In the formula, N represents the information channel number used by the brain to process information.

Kleinman further brought in optimal control theory to solve. But Kleinman model does not take into account the uncertainty of people's attention mechanisms, in the other word, there exist a problem that describe the uncertain human behavior with certain mathematical methods [12]. To solve this problem, fuzzy information theory should be introduced to establish new attention allocation model. Assume that m messages displayed to people can be indicated by one vector information:

$$\mathrm{Y} = [y_1, y_2, ..., y_m] \tag{2}$$

So, the status of intelligence information system in the brain is:

$$\Omega = \begin{bmatrix} w_1 & w_2 \cdots & w_m \\ p_1 & p_2 \cdots & p_m \end{bmatrix} \tag{3}$$

In the formula, w_i represents intelligence information processing system actual capacity for information y_i, reflects the strength of attention. p_i represents the probability of each message being accepted by the brain information processing system. The difference between w_i can be reflected by membership function $\chi(w)$:

$$\chi(w) = [\chi(w_1, \chi(w_2), ...\chi(w_m)] \tag{4}$$

Let f_i be the attention ratio assigned to y_i. If the person is an ideal observer, once the relative importance of vary information are known, the information will be allocate attention resource in accordance with the importance. So that the membership function $\chi(w)$ can be also expressed as the important degree of information.

$$f_i = \frac{\chi(w_i)}{\sum_{i=1}^{m} \chi(w_i)} \tag{5}$$

However, the fact is that people are not an ideal observer. The probability of information being accepted by the brain information processing system is not only related to the information's importance, but also relate to people's spiritual/psychological state [13]. Because of the lack of knowledge of man's own intelligence unreasonable design or coding problems, people can also has inadequate attention to important information or ignore the phenomenon. So, the attention mechanism of the human information processing system has fuzziness and randomness. Fuzziness means that all information on the importance of human judgment with ambiguity and uncertainty, it can not allocate attention resources by exact formulas [14]. Randomness embodied in each of the information in each eye can be noticed there is a certain probability. The proportion of attention allocation formula should be amended to read:

$$f_i = \frac{p_i \chi(w_i)}{\sum_{i=1}^{m} p_i \chi(w_i)} \quad (6)$$

The solution for the above formula is still need to introduce new theories and methods. (1) Model and solve the membership function. Intuitively membership function is a measure of the importance of information, but its core is the importance of people's evaluation awareness of information. According to Kleinman's assume that brain can process information awareness in parallel [15], it needs to establish people's importance valuation awareness model for parallel information. (2) Determine the random probability. The exact value of the probability is difficult to obtain actually, so it needs to make a reasonable estimate by fuzzy information theory. (3) Verify the credibility of the eventual establishment of attention allocation model from the experimental level.

III. Experimental Methods

A. Experimental Purpose

Usually a maintenance event includes the following work activities: preparation, fault diagnosis, disassembly, replacement, assembly, calibration and testing [16]. The purpose of this paper is the experimental use of eye tracking technology to measure saccadic eye movement behavior of the subjects in the implementation of fault diagnosis, disassembly , replacement and assembling four operating activities, analysis of data recorded eye movements, research the staff's attention allocation in different tasks scenarios and with different levels of situational awareness.

TABLE I. SWAT form and Kalyuga scale

	Level	Level Description		
Time Load	1	Often have free time		
	2	The occasional free time		
	3	Almost never have free time		
Mental effort Load	1	Rarely requires conscious mental effort		
	2	Need medium mental effort		
	3	Need a wide range of mental effort		
Mental tension Load	1	Rarely panic		
	2	Moderate tension		
	3	High and strong tension		
Difficulty	Very easy	Easier	Bit easy	normal
Score	1	2	3	4
Difficulty	Bit difficult	Difficult	Very difficult	
Score	5	6	7	

This study used a comparative design, and integrated application eye movement measurement and subjective assessment method experiment. Among them, the eye movements measured by measuring the quest chain , subjective evaluation method using questionnaires and psychological efforts subjective task difficulty scale , this scale is to measure the work load level during the experiment. Take together the data interpretation given stronger support. Mental effort questionnaire use SWAT (Subject Workload Assessment Technique) evaluation form. Subjective task difficulty using Kalyuga developed scales, using seven scoring system [17].

B. Experimental Conditions

1) Experimental Device

Main experimental apparatus is eye tracking system and virtual training platform maintenance Gun Disassembly 2. Gun Disassembly 2 needs to be installed on a computer training platform is installed SMI eye tracker before the experiment. SMI eye tracker can render text, images, videos and screenshots and other stimuli, and provides detailed information on eye movement data and time. Under Gun Disassembly 2 simulation platform can use a variety of models of firearms model, and the demolition and teaching and training the model guns.

SMI eye tracker is shown in Figure 1. RED eye tracker system structure as shown, including the iView PC test computer, Stimulus PC and two sets of infrared light source and camera mounted below. Subjects watched video on Stimulus PC, testers control the test video by iView PC computer. Camera installed at the bottom of the Stimulus PC records eye movement of subjects, and transfers record to iView PC. RED eye tracker has an advantage that subjects don't need to wear any device, the head can move freely within a certain range, the subjects feel comfortable, so that long time test is practical and the test data obtained are more accurate.

Figure 1. Gun Disassembly 2

Figure 2. SIM eye tracker

2) Experimental Subjects

12 people participated in the experiment, divided into A, B two groups, each group has 6 people. Gender Male, age 20-40 years old, all the normal vision or corrected visual acuity, binocular vision in 1.0. Subjects understand certain equipment maintenance knowledge, not including military fans firearms enthusiasts, the default rather try all the cognitive level. A group of subjects are experienced players firearms disassembly, as an expert pilot testing. Group B subjects were inexperienced players to novice status for testing.

TABLE II. DETAIL INFORMATION OF SUBJECTS

	TEC-09 Disassembly time		TEC-09 Disassembly time
Expert A1	1’09’’	Novice B1	3’35’’
Expert A2	1’05’’	Novice B2	3’45’’
Expert A3	1’14’’	Novice B3	4’15’’
Expert A4	1’19’’	Novice B4	3’55’’
Expert A5	1’13’’	Novice B5	3’15’’
Expert A6	1’25’’	Novice B6	2’15’’

C. Experimental Tasks and Procedures

Experimental task: the complete demolition of one TEC-09 model gun in the virtual platform.

Experimental procedure:

(1) All subjects were learning to operate Gun Disassembly 2 simulation platform, familiar environment and basic operating skills in simulation platform.

(2) Divide subjects into A, B two groups of six people each. Train A group to be expert subjects, B consisting of novice subjects.

(3) Explain subjects the eye tracker precautions and how to adjust the machine, so that the subjects are capable of the eye tracker calibration operation.

(4) Experiments. During the experiment, the subjects performed the demolition of firearms, if they meet problem and cannot going on, they can use the help information in the software. Subjects can click the Help button on the platform analog display help information. Eye tracker recorded the subjects gaze point information , the main trial record is the misuse times , the number of requests for help and the operation time during the whole operation.

(5) After the demolition of the experiment, participants were asked to complete questionnaires mental effort and task difficulty questionnaire.

(6) Each of the subjects should reset test system before the start of the experiment.

(7) Process the original experiment data, summarized the experimental results.

IV. EXPERIMENTAL RESULTS

In order to find the subjects’ attention distribution and summed up their glance patterns during disassembly task, we zoned interest region (AOI) on experiment eye movement data. By fixation point percentage, fixation duration percentage and average fixation duration fixation point three indicators in each AOI to determine the attention distribution of the subjects in the demolition process. Figure 3 shows a typical novice AOI in the process of dismantling the gun case, with five regions, with the picture changes during operation and timely adjustment AOI area, makes possible division of AOI keep the same position area from beginning to end.

Fig. 4 shows the fixation point distribution in each AOI of a typical novice when he disassembles the gun cartridge. Fig. 5 shows the fixation time percentage in different periods in each AOI during disassembling the gun cartridge of a typical novice. From the figures, we can see that novice’s fixation point appeared in all interest regions, the vast majority of the fixation point fall on the target area AOI4, which are gun cartridges disassemble parts. But in the demolition process, there is still a smaller portion of the fixation point drop in other zones.

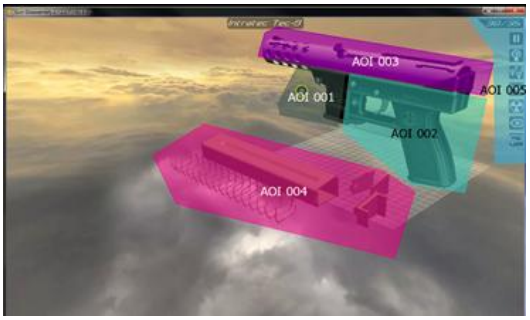

Figure 3. AOI zones of typical novice

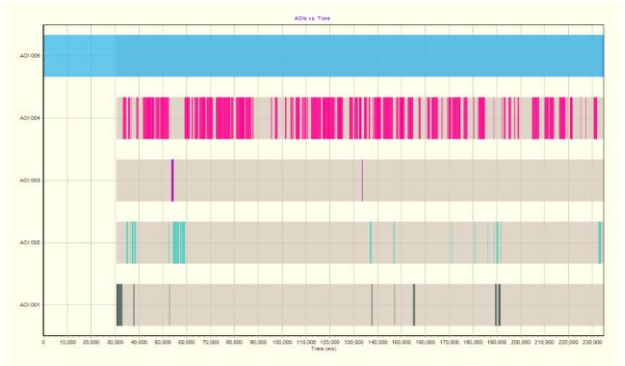

Figure 4. Fixation points in each AOI of typical novice

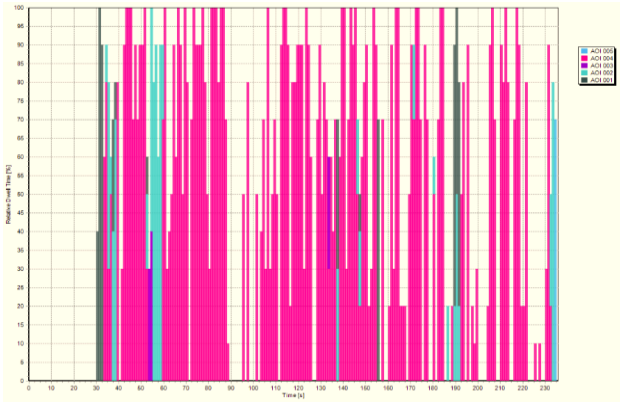

Figure 5. Fixation time percentage in each AOI of typical novice

Tables 3-5 are the detail time, average time and times for asking help of novice and expert subjects in the demolition process in three different regions. Table IV is time statistics table of novices and experts for completing task. Table 7 and Table 8 are T-test results processed by SPSS statistical analysis software.

TABLE III. SCHEDULE OF NOVICE

	Gun cartridge	Gun barrel	Gunstock	Total Time
Novice B1	21’’30	Regional switch	Regional switch	3’13’’20
Novice B2	9’’50	43’’20	27’’10	1’19’’80
Novice B3	20’’20	Regional switch	Regional switch	3’41’’20
Novice B4	20’’10	Regional switch	Regional switch	3’15’10
Novice B5	23’’50	Regional switch	Regional switch	3’50’’30
Novice B6	22’’40	Regional switch	Regional switch	3’08’’70
AVG	21’’50 (exp B2)			3’25’’7 (except B2)

TABLE IV. SCHEDULE OF EXPERT

	Gun cartridge	Gun barrel	Gun stock	Total Time
ExpertA1	9’’20	37’’20	20’’90	1’07’’30
ExpertA2	9’’00	30’’40	17’’50	56’’90
ExpertA3	10’’90	31’’30	18’’90	1’01’’10
ExpertA4	9’’10	31’’10	16’30	56’’50
ExpertA5	9’’30	31’’40	18’’50	59’’20
ExpertA6	9’’40	31’’20	17’’70	58’’30
AVG	9’’48	32’’10	18’’30	59’’88

TABLE V. THE AVERAGE TIME AND HELP VIEWS OF NOVICE AND EXPERT

	Gun cartridge	Gun barrel	Gun stock	Total Time	Help Views
Novice AVG	21’’50	Regional switch	Regional switch	3’25’’7	3
Expert AVG	9’’46	32’’13	18’’30	59’’88	0

TABLE VI. TASK TIME STATISTICS SCALE

		Expert Gun cartridge(s)	Expert Gun barrel(s)	Expert Gunstock(s)	Expert Total time(s)	Novice Gun cartridge(s)	Novice Total time(s)
N	valid	6	6	6	6	5	5
	N/A	0	0	0	0	1	1
AVG		9.4833	32.1000	18.3000	59.8833	21.5000	205.7000
Standard deviation		.70828	2.52349	1.55949	3.99521	1.45774	18.72845
Variance		.502	6.368	2.432	15.962	2.125	350.755
Min		9.00	30.40	16.30	56.50	20.10	188.70
Max		10.90	37.20	20.90	67.30	23.50	230.30

TABLE VII. SAMPLE T-TEST CORRELATION COEFFICIENT TABLE

		N	r	Sig.
Pair 1	Gun cartridge time	5	.846	.071
Pair 2	Expert Total	5	-.281	.647

This paper analyzes the experiment data through SPSS software, which is a professional Statistical analysis tool. The above tables display statistic scale result and sample t-test values. The table above reflects the detailed difference between novice and expert subjects in the course of the performance to complete task. Gun cartridge disassembly time zone t test coefficient indicates (sig.> 0.05, sig. (double side) =0), reflecting the difference between novice and expert strategies in the demolition process is significant. Due to the different scanning strategies in the demolition process, experts in the demolition process, tend to follow into the next area after the completion of a region sequentially, so the experts showed a strong sequential and efficient removal action. The novice glanced strategies are often switching between several regions, this switch also led to incoherent action and ambiguity on operating target, result in that it is impossible to calculate the demolition time of regions. By analyzing the eye movement video data and psychological questionnaire, the rule of attention from novice and expert subjects in the task can be obtained. Figure 6 shows the scanning map of novice and expert in the demolition process.

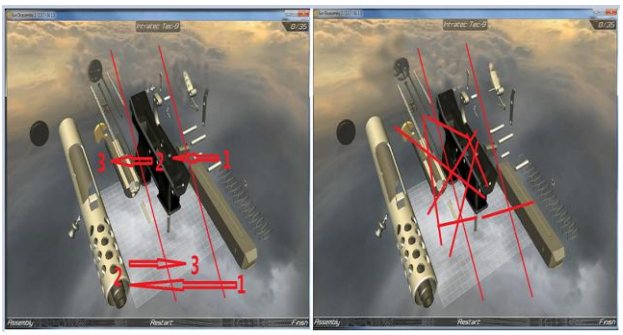

Figure 6. Scan map of expert (left) and novice (right)

As shown in the Figure 6, Experts shows a clear thinking throughout the demolition process, which can be grouped into two categories, they structure the three most firearms gun cartridges, gun butt, gun barrel for the division, followed by removing small parts of each structure. Gun cartridge removal is the starting point for all subjects, and then followed by the demolition of the barrel and butt. Such strategy has a performance of the overall division and orderly manner. After complete a part, attention is directly shift to the next part of the demolition, there is very little switching back and forth among the three regions. After starting the demolition,

TABLE VIII. SAMPLE T-TEST STATISTIC SCALE

		Differential pairs							
					95%Confidence interval				
		AVG	std	SE Mean	Lower limit	Upper limit	t	df	Sig. (double)
Pair1	Gun cartridge time	-12.30000	1.32665	.59330	-13.94725	-10.65275	-20.732	4	.000
Pair2	Total time	-146.06000	20.41453	9.12965	-171.40799	-120.71201	-15.998	4	.000

TABLE IX. EXPERTS SWAT RESULT

	Task	SWAT			Difficulty
		Time Load	Mental effort	Mental tension	Score
Expert A1	Gun cartridge	1	1	1	1
	Gun barrel	3	2	2	4
	Gunstock	2	3	2	4
Expert A2	Gun cartridge	1	1	1	1
	Gun barrel	2	2	1	2
	Gunstock	1	2	1	2
Expert A3	Gun cartridge	1	1	1	1
	Gun barrel	3	2	2	4
	Gunstock	2	2	2	3
Expert A4	Gun cartridge	1	1	1	1
	Gun barrel	2	2	2	2
	Gunstock	2	2	1	2
Expert A5	Gun cartridge	1	1	1	1
	Gun barrel	2	2	2	2
	Gun stock	1	2	1	2
Expert A6	Gun cartridge	1	1	1	1
	Gun barrel	2	2	2	3
	Gun stock	1	1	1	2

TABLE X. NOVICES SWAT RESULT

	Task	SWAT			Difficulty
		Time Load	Mental effort	Mental tension	Score
Novice B1	Gun cartridge	2	2	1	3
	Gun barrel	3	3	3	7
	Gunstock	2	3	3	6
Novice B2	Gun cartridge	2	1	1	1
	Gun barrel	2	2	1	4
	Gunstock	2	2	1	3
Novice B3	Gun cartridge	2	2	1	3
	Gun barrel	3	3	2	6
	Gunstock	3	2	2	6
Novice B4	Gun cartridge	2	2	1	3
	Gun barrel	3	2	2	6
	Gunstock	3	3	1	6
Novice B5	Gun cartridge	2	2	1	3
	Gun barrel	3	3	2	6
	Gunstock	3	2	1	6
Novice B6	Gun cartridge	2	2	1	3
	Gun barrel	3	3	3	7
	Gunstock	3	3	2	6

five of six novice subjects converted to other regions after completion of the demolition gun cartridges, and in the subsequent demolition of the barrel and butt demolition process, their attention glance showed relatively fragmented, fixation point switched frequently and disassembly operations also showed in the corresponding switch between different regions, the fixation point is not focused during the execution of the demolition operation, all theses reflects the demolition targets and operation is not clear enough.

The scanned track of novice and expert subjects also showed a more significant phenomenon. Experts were tested prior to glance into the next track in preparation for the removal procedure, the fixation point often appear early appearance on the demolition of the target, which will first glance at the track operator action step into dismantling the target area, and follow the action in the demolition process operation also showed a high degree of accuracy, thereby ensuring accurate and efficient of disassembly process. To observe the comparative novice subjects' glance trajectory, it is difficult to find a similar trajectory first glance into the target components of the operating action. Novice subjects are often need to scan in many area with exploratory operation action before ahead to the next task, in order to determine the corresponding remove target and remove action.

Based on the above two tables, we can get the following information: (1) throughout the demolition process, compare the workload of expert and novice, experts suffer smaller load than novice do in various

stages, so as the operating performance. (2) For both Experts and novices, work load and difficulty in the gun cartridges' demolition are all smaller than those in the other two parts. And in this easy part, the mental tensions of experts and novices have closer level. (3) In Gun barrel's demolition, both experts and novices show larger mental load and difficulty. These show that in the face of simple tasks, novice and expert have common characteristics on the work load, a simple task will not cause panic and anxiety levels of psychological stress on the operator, thus saving more resources. Among three stages, gun cartridge stage has the smallest difficulty and the minimum workload, however, the barrel stage is most difficult and brings the largest workload.

V. CONCLUSION

This article begin with an introduction of Equipment maintenance and human's attention, giving out a wholly view on these two aspects. Then the second section focuses on attention theories, from Kleinman's attention model, we further research the attention allocation model, to improve the model's accuracy and make it's solve easier, fuzzy information theory is imported.

Our core work is the experiment, theories mentioned above just give us basic theoretical foundation, what we want to find is about the attention rule in the virtual maintenance training. 12 subjects complete the demolition of one TEC-09 model gun in the virtual platform Gun Disassembly 2. Both qualitative and quantitative researches are taken, we use SIM eye tracker to record quantitative data, use SWAT (Subject Workload Assessment Technique) and Kalyuga scales to get subjective task difficulty/workload. After data processing and analysis by SPSS software, the following conclusions can be obtained about the attention activity in firearms disassembly tasks:

1. An expert show a more focused, clearer glance mode, while the novice eye glancing trajectory relative chaos.

2. Attention allocation strategies between novice and expert have significant difference, experts has predictive ability that provide guidance for the next step, which novice have none;

3. Scale investigation by the subjective mental effort and task difficulty questionnaire validated test results with the subjective experience of being consistent.

The above points are also the reason that experts have better performance in the operation time, operation accuracy and operating performance. This study defined the differences between different users in maintenance training and the reasons for differences, providing a positive significance for maintenance training system design and personnel training.

VI. FUTURE WORK

Future work will consider about an improved interaction design for maintenance training system, the result of this paper can provide a basis. The interactive behavior in maintenance training is complex and various, we just hold the attention shift rules as a point to explore. User behavior in real environment not the virtual platform may give out more valuable data, so in the future work, we can design some experiments in Realistic scenarios. Other experiment devices like Electrical equipment are helpful. To carry out the plan, there is a lot of work to do, including human-computer interaction, interface design, system development, user study and so on. Also, study in this paper is not perfect, it still can be improved.

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