Gaze Metrics for Efficient and Safe Operations of Hemodialysis

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ABSTRACT
This paper presents an application of eye tracking approach to cognitive task analyses of hemodialysis operation conducted at real working places in a Japanese hospital. In the study a series of observations was performed, where three clinical engineers' gazes as well as their behavior was recorded for five consecutive months. Two of the engineers were novices who had just begun their work at the hospital a few days before the observation started. Another engineer was an expert who had more than sixteen years of experience.

As a framework of cognitive task analysis, we developed a six gaze metrics that are closely connected with the cognitive aspects in efficient and safe operations of the hemodialysis. Trends of each novice engineer's information acquisition along with learning during a set-up task that is a part of hemodialysis operation were analyzed on the basis of the six gaze metrics. Several issues/implications on the novice engineers' adaptation to the hemodialysis operation task was discussed after the study.

Author Keywords
Gaze metrics, eye tracking, hemodialysis machine, learning processes.

ACM Classification Keywords
H.5.2 User interfaces

INTRODUCTION
Clinical engineers performing hemodialysis operation shift their gazes between many areas like small indicators, controllers, tubes and so forth as well as change in medical staffs. It can be expected that understanding of when and why such shift of gazes occurs provides great insights about skills or knowledge that are needed to carry out such tasks both efficiently and safely.

In the medical domain, some researchers have argued that the eye tracking approach involves great potentials to reveal skills and know-how (e.g., [1-4, 9, 10]). However, the application of eye tracking to issues in real environment is still rare. There are three primary reasons for this: First, recording eye tracking data in real-world environments seems to have some potential for adverse influence on performance. Caused by this, most of hospitals or clinics are reluctant to adopt eye tracking recording in their working places. Second, analyses of eye tracking data are basically labor-intensive (e.g., [8]). Such analyses require very time-consuming in-depth cataloging of fixations, fixation durations, fixated areas, and so forth from video recordings. Thirdly, though interpretation of eye-tracking data is of great difficulty, there are very few analysis methodologies that can be widely used for knowledge-elicitation or behavior analysis in various domains. This means that every investigator has to develop appropriate analysis framework unaided in order to interpret data generated in his/her research.

In this paper, we describe a pilot study performed in a hemodialysis operation room on the behavior of clinical engineers during the set-up of hemodialysis machines. We developed gaze metrics representing clinical engineers' attention allocation during information acquisition, and applied the metrics to the cognitive task analysis of novice engineers' learning in the set-up tasks. The gaze metrics as well as the underlying idea proposed in this paper implies the principle that guides how eye tracking data in some cognitive tasks should be processed.

TASK FOCUSED IN OUR STUDY
To perform hemodialysis, a clinical engineer is firstly required to do a set-up task of the hemodialysis machine. In this set-up task, each engineer has to install the appropriate tubes, open a valve in venous side in order to do priming, and check the current status of the machine before starting hemodialysis (see Figure 1). Set-up task is recognized as one of the most critical tasks in whole hemodialysis operation since the errors committed in this task may cause serious injuries to the patient.

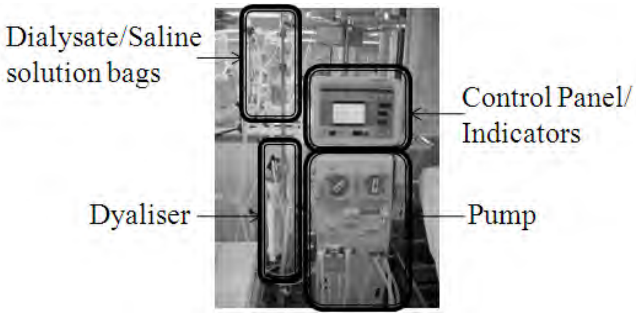

Figure 1. Hemodialysis machine.

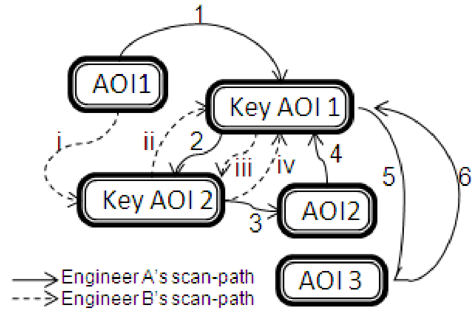

Figure 2. Schematic example of scan-paths among AOIs.

GAZE METRICS

For analysis of eye tracking data during hemodialysis operation, we adopted the gaze-based metrics shown in Table 1. As explained in the table, each metric is directly connected to the aspects relating to efficient and safe information acquisition during the set-up task. The detailed explanation about each metric is described below.

Aspect for evaluation	Corresponding gaze metrics used in this study
1. Information acquisition from all the task-related information	
1-1. How much did the engineer try to acquire the information?	→ *Number of gazed AOIs*
1-2. How long did the engineer spend time for each information?	→ *Mean fixation duration per AOI*
1-3. How redundantly did the engineer inspect information?	→ *Mean number of fixations per gazed AOI*
2. Information acquisition from key information that is critical in the current task	
2-1. Did the engineer inspect all the key information?	→ *Coverage rate of key AOI*
2-2. Did the engineer select the key information efficiently?	→ *Rate of key AOI included in gazed AOIs*
2-3. Did the engineer inspect key information redundantly?	→ *Mean number of fixations per key AOI*

Table 1. Gaze metrics.

Gaze Metrics for Information Acquisition Processes from All the Task-Related Information

We firstly focus on engineers' information acquisition from all task-related information. In the hemodialysis machine, we could identify 24 areas of interests (AOIs), all of which seemed to be related to the set-up task. Based on the AOIs, we calculated the following metrics:

Number of gazed AOI (area of interest). This metric is concerned with a question how much information an engineer tries to acquire within a given task. This can be obtained as net number of all of gazed AOIs within the set-up task. Since 24 AOIs were identified in the hemodialysis machine, the maximum numerical value of this metric is 24 in this study. Figure 2 shows a schematic example of the scan-paths of two engineers. Two out of five AOIs are identified as key AOIs, which will be explained below, in this example. In this example, the metric for engineers A and B are obtained as 5 and 3, respectively.

Mean fixation duration per gazed AOI (area of interest). This represents how long an engineer spends time in order to process each AOI's information. This metric can be obtained as an average of a single fixation's duration over all the gazed AOIs.

Mean number of fixations per gazed AOI (area of interest). This metric reflects our expectancy that reliable activity can be ensured by multiple inspections, and not only by a single inspection on required information. This metric indicates how many times a gazed AOI was fixated in average. In the example shown in Figure 2, the metric for engineers A and B are obtained by (1+4+1+1+1)/5=1.60 and (1+2+2)/3=1.67, respectively.

Gaze Metrics for Information Acquisition Processes from Key Information

Secondly, we focus on the information acquisition processes from critical information (in this paper named "key information") that are necessary at the moment. The procedure for identifying such critical information (i.e., "key AOI") will be presented in the following chapter.

Coverage rate of key AOI. This metric is relating to how much critical information is successfully gazed by an engineer during the task. This is calculated as the number of key AOIs that are actually gazed divided by the total number of key AOIs. In the example shown in Figure 2, this metric for both of engineers A and B is 1.0.

Rate of key AOI included in gazed AOIs. This metric derives from a question how efficiently an engineer can select the key AOIs. This metric is calculated as the number of gazed key AOI by a specific engineer divided by the number of gazed key AOI. In Figure 2, this metric for engineers A and B are calculated as 2/5=0.4 and 2/3=0.67, respectively.

Mean number of fixations per key AOI. The idea of this metric corresponds to that of the *Mean number of fixations per gazed AOI*. This metric indicates how many times a key AOI was fixated in average. In Figure 2, this metric for engineers A and B are calculated as (4+1)/2=2.5 and (2+2)/2=2.0, respectively.

DATA COLLECTION

Three clinical engineers working at a Japanese hospital was observed during this study. Two engineers (E1 and E2) had just started to work just after their graduation from

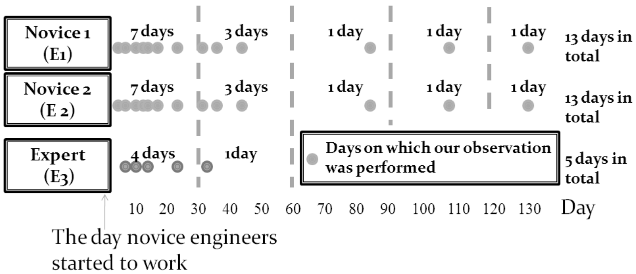

Figure 3. Observation procedure.

Figure 4. An engineer participating in our observation.

university when the observations began. Both of their age was 23 with less than 1 month experiences of the hemodialysis operation. The last engineer was an expert who had more than 16 years experiences of the operation. Figure 3 illustrates the observation procedure. As shown in the figure, we performed the observations for five consecutive months (see Figure 3).

We observed the set-up task in real hemodialysis operation. Before the task, we asked engineers to take a SMI eye tracking system and to perform calibration. The SMI's system was determined to have a spatial accuracy of 0.5-1.0°, and the sampling frequency was 60Hz. We repeated the calibration if the calibration was off by approximately more than 2.0°. The calibration procedure took around 5-10 minutes in total for each engineer. Then we started to record their eye movement as well as video recording of their behavior (see Figure 4). As explained before, most of Japanese hospitals, in general, are reluctant to adopt eye tracking recording in their working places. This observation could be carried out by a special permission given from people responsible for the operation room, who has a great understanding of research in Human Factors area. To perform the observation smoothly, we explained about the eye trackers to patients in advance, which allowed us to avoid undesired conflicts with them.

RESULTS

Before analyzing the two engineers' (E1 and E2) data, we firstly identified what AOIs were gazed by the expert engineer. According to previous works, the use of eye movement as expert's skill information is recognized as very effective in training in the field of aircraft inspection [7], assembly line [5], and so forth. In such application, an expert's eye movement is taken as an ideal eye-gaze sequence. Considering this, we determined that the AOIs gazed by the expert engineer are "key AOIs" for each of three subtasks (i.e., install tubes to appropriate areas, to open a valve in venous side, and to check all the current status of the machine).

Transitions of the gaze metrics for information acquisition processes from all task-related information and from key information with days are shown in Figures 5 and 6, respectively. As for number of gazed AOI, show for both engineers (E1 and E2) a decreasing tendency along with their experience increases (see Figure 5 (a)). Especially, E2 seems to succeed in reducing unnecessary gazes within less than 40-day experience, though E1 tends to look at too many AOIs in the identical period. From time needed to process information view, both engineers do not seem to be acquainted with processing information efficiently within the observation period (see Figure 5 (b)). As found in Figure 5 (c), E1 gazes at each AOI more frequently, whereas E2 seems to become stable (approx. 1.0) by 40-day experience. The results mentioned above may indicate that the E2 could adapt well to the set-up task compared with E1. The results may also indicate that some follow-up training for E1 could be necessary, with close inspection of the set-up task in order to compensate for E1's lacking skills.

As for metric "Coverage rate of key AOI", both engineers do not show improvement in the observation period. The mean values of the metric for E1 and E2 are 0.399 and 0.343, respectively (see Figure 6 (a)). At the very early learning stage, the efficiency in selecting key AOIs represented by "Rate of key AOI included in gazed AOI" seems to be improved by E1 (see Figure 6 (b)). Along with the 80-120 days experience, both of engineers seem to show stable values (around 0.6-0.8) in this metric. As seen in Figure 6 (c), E1 gazes at key AOIs very frequently at the early period in learning, and shows sudden drop just after

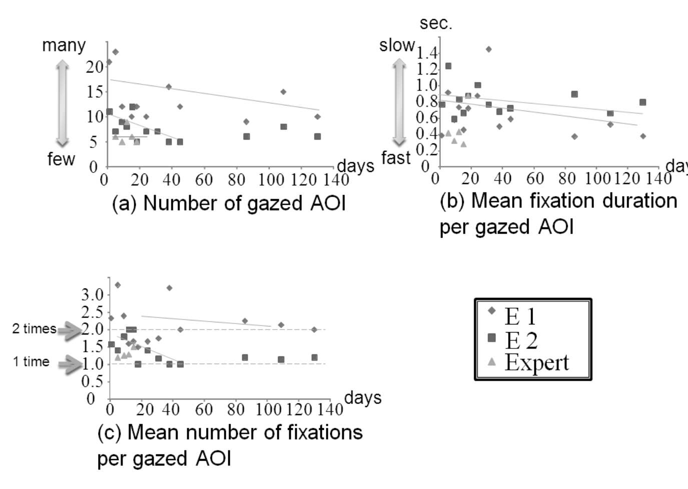

Figure 5. Transitions of gaze metrics (task related information).

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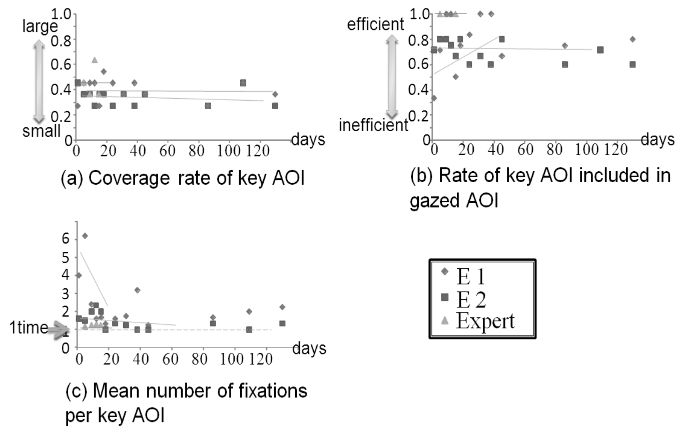

Figure 6. Transitions of gaze metrics (key information).

20-day experience. E2 on the other hand, shows relatively stable values in the same period. Mean values of the metric from 40 to 140 day of experience for E1 and E2 1.79 and 1.17, respectively. Among the results mentioned above, we think that the tendencies found in the metric "Mean number of fixations per key AOI" are relatively problematic. The values of the metric having less than 2.0 indicate that the most of key AOI are likely to be inspected less than twice. This implies that opportunity of revision of the inspection error may be lost when some error occurs at an initial inspection of a key AOI. From this result, we suggest that the novice engineers should be instructed to perform multiple inspections to key AOIs. In addition, the effect of the instruction should be evaluated by applying our metric "Mean number of fixations per key AOI".

CONCLUSION

In the present paper, we propose a six gaze metrics and a calculation procedure for analyzing hemodialysis operations. The metrics were closely connected with questions that arose from cognitive aspects in efficient and safe operations. We think that the gaze metrics as well as the underlying idea proposed can be applied to other tasks classified into "well-defined" cognitive tasks, meaning that the structure of task such as task goal, constraints, working procedure and so forth can be described in advance. The proposed metrics were applied to analysis of the two novice clinical engineers' learning processes in the set-up tasks included in the hemodialysis operation. Examining the novice engineers' performance elicited by the metrics, we could identify differences of tendencies in information acquisition processes with learning, especially the task-related information processes were notable.

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