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Cognitive Ergonomics and Informatory Load in Anesthesia

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Abstract

The anesthesia workplace can be regarded as a complex human-machine-system (HMS). In this information-intensive “cockpit” the operator has to handle several devices. Not only visual but also auditory cues have to be integrated in the action-control-loop. It´s obvious that in some stressful and complex situations, a perceptual and cognitive overloading of the anesthetist could occur and therefor inhibit an efficient and save interaction. The design of the interfaces and the form of information presentation has a significant impact on these aspects.
The contribution presents the possibilities of the new methodical approach “iFlow Analysis” (information-flow) to observe cognitive ergonomics and informatory load in such HMS. In our exemplary observation we used an eyetracking-system to evaluate the user interactions in a simulated scenario and in a field (thyroidectomy and exploratory laparotomy) situation. All incoming visual and auditory signals were observed during the procedure of anesthetic guidance. The interactions have been integrated in the so called iFlow Chart to evaluate the density of information presentation. In addition informatory load has been measured by the dynamic changes of pupil size.

1 Introduction

In 2007 the “Decade of the Mind” Initiative constituted the first milestone for a global interdisciplinary research in understanding the “mechanisms of the mind” [1]. Also in ergonomics science the cognitive aspects of the users gained significance. Hence the Human Factors and Ergonomics Society has its own technical interest group called “Cognitive Engineering and Decision Making” [2]. In this domain the analysis and evaluation of mental workload and interface design approaches to reduce mental workload are typical research fields. Related to this, cognitive ergonomics describes the fitting of the cognitive skills of the user to the task.
Especially in work domains where tasks are rather kind of mental than physical it is necessary to take care of cognitive ergonomics. Mostly those human-machine-systems (HMS) are characterized by a high density of input and output information-flows (iFlows). For this reason we call such HMS “information-intensive” and the mental load due to information input and output “informatory load”.

1.1 Information-intensive Anesthesia

The anesthesia workplace can be regarded as a complex and information-intensive HMS. Hence it is often compared to an airplane cockpit. Not least because the load depending on the situation is quite similar: phases of high information density (like take-off or landing) alternate with those of low density (like instrument flight), which in turn can be interrupted by critical events.
Like in an airplane the operator in the “anesthesia cockpit” has to integrate information from several technical (e.g. anesthesia monitor) and biotical (e.g. patient) displays (input) and also to act by verbal-, motor- (e.g. handle several controls) or gesture activity (output) to get the right performance of the HMS (see image 1). Concerning the technical interfaces in the anesthesia workplace, aggravating circumstances are given similar to an airplane cockpit: the devices in the “anesthesia cockpit” are not exactly arranged functionally and are mostly a reunion of products of different manufacturers. By this means both, the visual and auditory cues of input information and the haptic/motor-activity cues of output information do not arise from an overall concept and are not coordinated with each other.

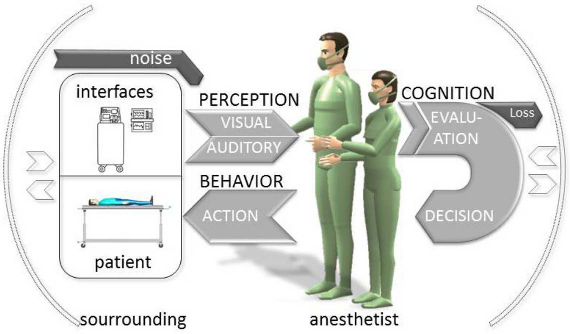

Image 1 Abstract anesthesia action-control-loop

It is obvious that in some stressful and complex situations, a perceptual and cognitive overloading of the anesthetist could occur and by this reason inhibit an efficient and save interaction.
The design of the interfaces and the form of information presentation has a significant impact on these aspects. To get an insight in the way the anesthetist uses the information of the “cockpit” and especially which information is relevant and which one is rather disturbing the performance, we created a methodological approach by which we are able to analyze the information-flows between op-

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erator and “cockpit” and measure the informatory load of the operator. This leads to important interface requirements which have to be taken into account in the design process.

2 iFlow Analysis

The „iFlow Analysis“ is a methodological approach for the evaluation of information-flows between the operator of a HMS and the whole variety of biotic and technical communication partners. The focus of Industrial Design Engineering is the improvement of communication with the technical interfaces by fitting it to the operator skills and scopes depending to the situation and the task – this is often expressed by the so called usability of the devices. The titling of iFlow on the one hand depends on the investigation objects – the flows of information – and on the other hand on the objective to design technical interfaces that keep the operator in an optimal state of flow [3], the state between high (overloading) and low (boredom) information density.

2.1 Possibilities and limitations

There is a wide range of tools and methods in the field of usability analysis and evaluation. Four accurate categories that can be found in engineer standards [4] try to cluster this plenty of methods. These categories are:

- Subjective observations
- Analytic observations
- Performance observations and
- Psycho-physiological observations.

The iFlow Analysis represents a methodological approach which combines all the four categories to get the best observation output. The synergy effects by combining the categories are addressed in various publications.

The adaptivity of iFlow allows micro- and macro-ergonomic applications. This is made possible by abstracting all the interactions to the basic level of information-flows. The adaptivity is given by the choice of interaction parameters based on an ontology of the human-machine action-control-loop. This ontology is applicable and adaptable to various HMS.

An important advantage of iFlow over most usability methods is the possibility to get the real-time data of the human-machine-interactions within a context of other process variables embedded in an overall situation. This generates data that cannot be found in a scenario-based lab observation.

The operator himself remains the unknown quantity. Every situation is specific and every operator acts different even in the same situation. Although it is possible to measure the operators current load by psycho-physiological measurement, it is not possible to get an insight in the operators mind and thoughts (applies as long as fMRI cannot be used in real-time context). The behavior observation does not bring out internal states like motivation. Hence it is necessary to review the data in collaboration with the operator.

2.2 Specification

The data needed for the iFlow Analysis is collected by video and audio recording (incl. Eyetracking) for analytic and performance observation, by standardized pre- and post-interview with the operator for subjective observation and by electrocardiography (ECG), pupilometry or electro dermal response (EDR) for psycho-physiological observation. By ECG it is possible to observe heart rate variability or in extension with photo-pletysmography pulse rate. EOG allows the derivation of pupil diameter and EDR the galvanic response of the skin. In all three measurements the objective is to get data about the current workload of the operator. The detection of mental workload by these types of measurement is proved and meanwhile part of all textbooks in usability observation. In which way mental workload is comparable to informatory load or emotional load remains an open question.

All the data is integrated into the so called “iFlow Chart” which visualizes the information-flows and the density of input and output information for the whole observation. In many cases correlations of information density and psycho-physiological parameters are recognizable. Image 2 shows the basic composition of the iFlow Chart with an exemplary choice of interaction parameters.

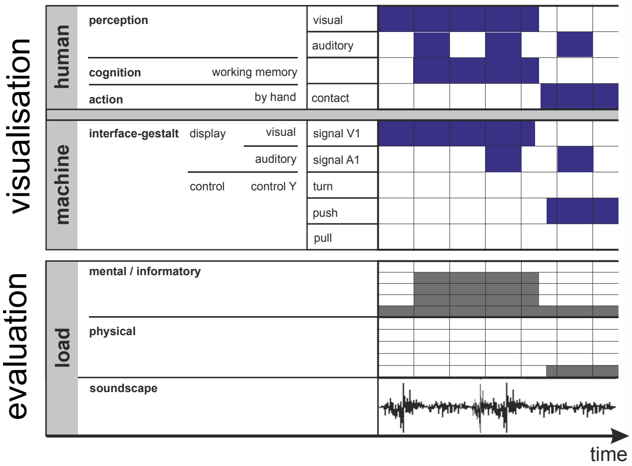

Image 2 iFlow Chart

The visualization is generated by the video data. The visual channel can be extracted of the eye-tracking data. For evaluating the information used, it is necessary to track the gaze of the operator. Data of cognition can be quantified by the also grabbed pupil diameter (see 2.2.2). These human interaction parameters are in a cause-and-effect-chain with the parameters of the machine (interface elements like displays and controls) either active or passive.

The evaluation of the information-flows refers to mental/informatory or input load and physical or output load. Noise of the surrounding like the soundscape has also been taken into account in some cases of observation.

2.2.1 Information density

Density as a characteristic of complex operations in anesthesia was already handled in the macro-ergonomic observations of T. Manser [5]. Based on this concept iFlow-

Analyses specifies a more detailed level of information-flows in human-machine-interactions. With these basic parameters the objective of the iFlow-Analysis is not primarly to detect ineffectiveness but rather to gain knowledge for the design of reliable and load-reduced interactions.

The analysis of information density of input and output allows to draw conclusions from the informatory load. Here it is important to contemplate the operators task objectives and hence the overlapping of tasks. Due to the Multiple Ressource Theory of C. D. Wickens [6] the human operator has several different pools of resources which are represented by each line of the human operator parameters in the iFlow Chart. It is now essential that depending on the nature of the task, the human operators´ pools of resources are processing information sequentially if the different tasks require the same resources to ensure a reliable and efficient interaction. On the other hand, when the tasks require different resources the pools can be served simultaneously.

2.2.2 Informatory Load

In our study we used pupilometry to detect informatory load. Several research has been made to the detectability of mental workload via measurement of pupil diameter i.e., by Nobel Prize Winners D. Kahneman and A. Tversky [7]. E. H. Hess even mentioned the pupil as a “window to the soul” [8]. By the use of the eyetracking-system to examine the interaction parameter “vision” it was possible to record the dynamic change of pupil size simultaneously. The pupil size was taken by a horizontal and vertical linear measure with the sampling rate of 50 Hz. The dynamic change of the pupil size gave information about the mental state of the operator in the way that the larger the pupil size was, the more activated was working memory. This in turn means that the operator was loaded by the internal information processing process. In such non-automated (non-routine) action-sequences, combined with a stressful situation, interaction errors may occur with increased probability.

2.3 Application and Evaluation

Before the clinical application could start, it was necessary to test the eyetracking-system on a preclinical platform. For this purpose some observation of simulated critical events in anesthesia was made in the Center for Patient Safety and Simulation (TüPASS) at the University Hospital Tuebingen. The findings in consideration of installation and adjustment of the eyetracking-system on the issues of an anesthetist were required for the field observation. It was also inevitable to check the reliability of the system in situations of stress. Since the anesthetist had to wear a helmet where the eyetracking-system was fixed, we had to test, if the whole equipment does not disturb the anesthetist even in hectic action.

Afterwards, the exemplary field observation took place at the Klinikum Konstanz. Image 3 shows the layout of the setting in the OR (observers yellow colored). The Anesthetist´s interactions were analyzed during two surgical interventions: a thyroidectomy (duration 01:08:37) and an exploratory laparotomy (duration 01:58:44). All input information-flows of visual and auditory signals were observed during the procedure of anesthetic guidance.

In connection with the data acquisition the information-flows were integrated in the iFlow Chart. The pupilometry data had to be adjusted and adapted to the timeline of the iFlow Chart. Because of the huge data volume, first step was the elimination of the blinkers and the data allocation to a confidence interval. After that, means were calculated for each second of observation and the aberration to the overall mean has been integrated into the iFlow Chart. Based on this analysis data, evaluation of informatory load and cognitive ergonomics of information presentation could be made for selected scenarios.

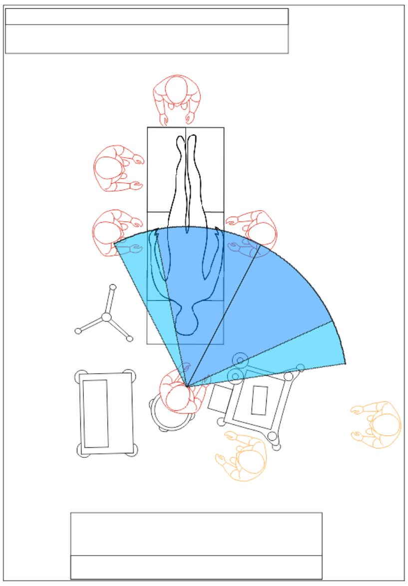

Image 3 Observation setting

3 Results

Three scenarios have been extracted from the whole observation and analyzed with iFlow:

- Scenario 1: mask ventilation
- Scenario 2: intubation and
- Scenario 3: creating a central venous catheter.

All scenarios have been performed by an experienced anesthetist and took place at his start of work. The iFlow Chart showed both times of low density and high density of auditory and visual information. User errors did not occur.

By analyzing the visual scan path in all three scenarios, it was measurable that visual focus on the patient monitoring system was different in each scenario: 11.1% in scenario 1, 23.7% in scenario 2 and 5.3% in scenario 3. Image 4 shows an example of a scan path. The cross shows the location of the gaze at this moment. It is visible that in this situation the scan path drifts from the pulse curve to blood pressure over to the blood pressure curve, back to blood pressure, to the pulse curve, and again on the blood pressure curve (see image 4).

It was striking that mostly the curves have been viewed first and second the numeric values. Related to this, viewing time at the curves have been shorter compared to the numeric values. This could be verified by the post-interview with the anesthetist whose testimony was, that the numerical values are important for the next steps in treatment whereas the curves give a qualitative trend of the past seconds. Also noticeable was that the anesthetist checked the pulse and oxygen saturation mainly.

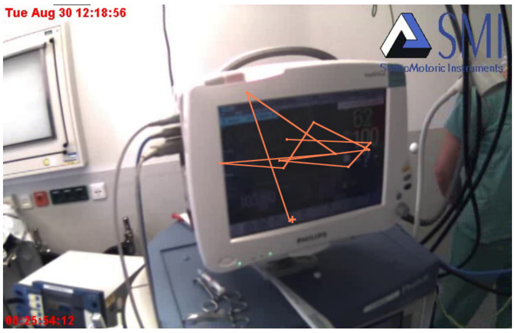

Image 4 Scan path observation

The evaluation of the iFlow Chart showed an uncomfortable high auditory load due to phases of incoming warning signals of infusion pumps and oxygen saturation. At this time a widening of the pupil could be monitored (see image 5 – scale-unit pixels) what can be seen as (auditory) informatory load.

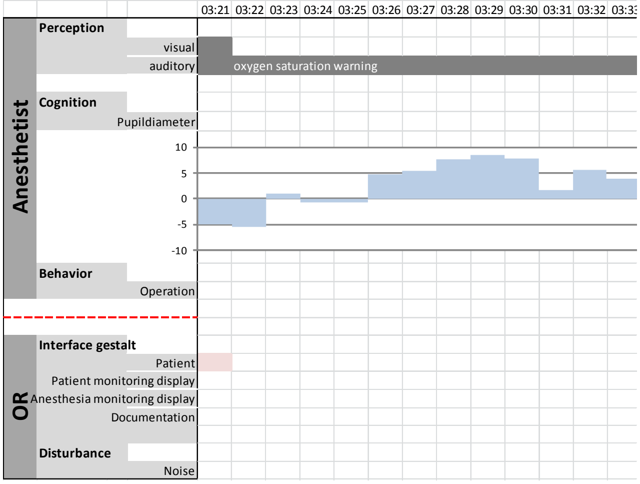

Image 5 Informatory load of auditory signals in scenario 1 (excerpt of iFlow Chart)

Comparing the three scenarios in matters of informatory load, the mean of pupil size increased in each scenario:

- Scenario 1: 33.99 pixels (approx. 3.01 mm)
- Scenario 2: 36.07 pixels (approx. 3.19 mm) and
- Scenario 3: 36.27 pixels (approx. 3.21 mm).

Because of the individual (e.g. age, constitution) and situation depending (e.g. lighting conditions, time of day) factors which have an influence on the standard value of pupil size, there are no absolute values available that allow a statement with regard to limitations of informatory load. The increasing of measured pupil size in all three scenarios could be brought into connection with the analyzed density of visual information-flow. In Scenario 3 qualitative more visual interactions and changes of gaze from the patient to the patient monitoring display could be observed.

4 Conclusion

Anesthesia workplaces need a revision towards cognitive ergonomics and informatory load. Hence it is necessary to restructure and harmonize the arrangement of the devices and the design of the human-machine-interfaces in the “anesthesia-cockpit”. This must be addressed by systematical analysis and design improvements. Reviewing our exemplary field observation some methodical modifications should be taken into account in following studies. At first the psycho-physiological observation should be expanded by using ECG in addition. The pupil size data was artifact-prone and showed large standard deviations after calculating the means. Also a less disruptive eyetracking-system should be used. There are systems available which can be fixed on a headband.

The way of visualizing and documenting the interaction data with the help of the iFlow Chart showed assets in communication at the interdisciplinary debriefing. The assessment of the results is only possible in a descriptive way so that more observations should be made to get to substantive evidence for the evaluation of the human-machine-interfaces. Altogether the iFlow Analysis showed high capability to detect both, bottlenecks and insufficient information presentation. These findings bring up important functional specifications for the design of the human-machine-interfaces.

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