Visual attention of anaesthetists during simulated critical incidents

C. M. Schulz 1*, E. Schneider 3, L. Fritz 1, J. Vockeroth 3, A. Hapfelmeier 2, T. Brandt 3, E. F. Kochs 1 and G. Schneider 4

1 Department of Anaesthesiology and 2 Institute of Medical Statistics and Epidemiology, Technische Universität München, Ismaninger Str. 22, D-81675 München, Germany
3 Institute of Clinical Neurosciences at Ludwigs-Maximilians-Universität München, Marchionistr. 15, D-81377 München, Germany
4 Department of Anaesthesiology I, University Witten/Herdecke, Helios Klinikum Wuppertal, Heusnerstr. 40, D-42283 Wuppertal, Germany

* Corresponding author. E-mail: anaesth.sekretariat@lrz.tum.de

Editor’s key points

- Visual attention, as an underlying process of situational awareness (SA), was studied in anaesthetists attending simulated critical incidents.
- 20% of the attention was directed to the patient monitor; this increased to 30% during critical incidents.
- Manual tasks increased from 21% to 25% in experienced anaesthetists and decreased from 20% to 14% in inexperienced anaesthetists.
- This small sample study provides important evidence of how experience changes SA of anaesthetists during simulated critical incidents.

Background. Situation awareness (SA) is considered to be an important non-technical skill for delivering safe anaesthesia. The spatial distribution of visual attention (VA) is an underlying process for attaining adequate SA. In the present study, a novel technology was used to assess the distribution of VA in anaesthetists delivering anaesthesia. The impact of a critical incident on VA in relation to individual experience is analysed in a descriptive and exploratory manner.

Methods. Fifteen anaesthetists induced general anaesthesia in a full-scale simulator while wearing a head-mounted eye-tracking camera system. After an uneventful session, workload was increased in a randomized order by simulation of a critical incident in the second or third session. Eye tracking was used for the assessment of individual’s distribution of VA to monitors, patient, and environment. A post hoc video analysis revealed information about the spatial distribution of VA. Descriptive statistics and exploratory analysis were used.

Results. Twenty per cent of VA was directed to the patient monitor (30% during critical incident scenarios, \(P = 0.003\)). The more experienced anaesthetists (more than 2 yr of work experience) increased the amount of time dedicated to manual tasks from 21% to 25% during critical incidents, whereas the less experienced decreased from 20% to 14% (\(P = 0.061\)).

Conclusions. Distribution of attention is different during anaesthesia induction with critical incidents compared with uneventful anaesthesia induction. Less experienced anaesthesia providers spend more time on monitoring tasks. Further investigation in confirmatory designs is needed.

Keywords: anaesthesia, general; anaphylaxis; education; eye tracking; patient simulation; situation awareness; visual attention

Accepted for publication: 3 February 2011

Non-technical skills are important for ensuring patient safety. They can be subdivided into four main components: decision-making, situation awareness (SA), task management, and team work.1–3 Endsley and Garland4 defined SA as the perception of the elements in the environment within a volume of time and space (level 1), the comprehension of their meaning (level 2), and the projection of their status in the near future (level 3). The distribution of attention for the acquisition of information is an underlying process of attaining adequate SA.4,5

In anaesthesia, a huge amount of information is presented visually. However, little is known about the anaesthetists’ distribution of visual attention (VA) to gather the relevant information for sufficient SA. Their attention elects the relevant sources of information from the sensory input and determines which information will be perceived (perception) and processed to form anaesthesiological SA.5,5 This process is performed by the working memory that takes into account medical knowledge, expectations, mental models of the actual patient’s state, guidelines, and the goals of treatment.4 SA is considered to be a prerequisite of decision-making, task management, and—finally—performance.4

Knowledge about the relation of VA to SA and performance may result in efforts to improve the design of monitors,
anaesthesia machines, and workplaces. In addition, knowledge about VA in specific critical situations may be used for the development of curricula for SA training. In a first feasibility study by Schulz-Stübner and colleagues, the concept of eye tracking was evaluated for the assessment of the distribution of VA in three cases of general anaesthesia in a real operation theatre environment. The authors emphasized the importance of standardized conditions for the design of prospective study designs.6

In pilots, differences between novice and experts were found with regard to their gaze behaviour in the way that experts have more automatized skills in extracting information7 and tend to have more frequent fixations with lower dwell time.8 In further studies, a decrease in fixation duration was found during workload increase.9 10

In the present study, we used a novel technology to assess the distribution of VA in simulated anaesthesia inductions with and without critical incidents. The impact of a critical incident and the impact of the participant’s experience level on VA are analysed in an exploratory manner. The behaviour of looking at the patient monitor is analysed with respect to the subjects’ experience. Furthermore, anaesthesiological scan paths were identified in a descriptive assessment.

Methods

Study design

The study was approved by the Ethics Committee of the Technische Universität München, and informed consent was given by all participants. The study design, the sample, and the results of the variables heart rate, pupil size, saccade amplitude, and fixation duration related to workload increase by simulating critical incidents have been published in a previous study.10 In short, a convenience sample of 15 anaesthesiologists of the Department of Anaesthesiology participated in this randomized, cross-over trial. They had to wear a head-mounted eye-tracking camera system (EyeSeeCam10–12 Fig. 1) while inducing general anaesthesia at a high-fidelity simulator (HPS®, Meti, Sarasota, FL, USA). The occurrence of a critical event was randomized in session II, just after the participants had entered the simulator room. The critical incident consisted of a severe anaphylactic reaction after administration of the hypnotic. Two simulator scripts were programmed to guarantee comparable simulator conditions. Script A operated the mannequin during uneventful induction (‘uneventful sessions’). Script B operated the mannequin during critical incident states. Detailed information about study design, simulator environment, and the simulator scripts is given in the pilot study.10

Data collection

A head-mounted, mobile, and battery-driven eye tracker was used to record the targets of gaze of the anaesthesiologists during the sessions (Fig. 2). Video streams of a head-fixed scene camera with a black point denoting the current region of interest (analysis video) were stored to hard disk. In addition, eye rotation vectors13 were recorded at a sampling rate of 304 Hz. For analysis, the rotation vectors had to be processed in two steps. First, a custom-made Matlab macro (Mathworks, Natick, MA, USA) extracted starting time and ending time of each fixation that lasted longer than 100 ms.10 16 Secondly, this timing information about fixations was merged with the analysis video in a software tool for video annotations (ANVIL, DFKI, Saarbrücken, Germany, http://www.anvil-software.de). Different regions of interest (ROIs) were empirically classified a priori and divided into the groups monitoring tasks, manual tasks, and other (Table 1). In ANVIL, the investigator allocated one of 23 ROIs to each of the temporally predefined fixations. He was then able to jump from one fixation to the next by mouse clicks, to observe the corresponding video scene, and to select an adequate ROI from a menu. Frequently, the same ROI was interrupted by saccades, for example, when the anaesthetist read the patient’s record (Supplementary Fig. S1). Therefore, a second macro combined data of subsequent and identical ROIs and corresponding times to one ROI per row. Similar to the analysis of pilot’s scanning behaviour,15 a scan path was defined as a pattern of four subsequent ROIs that appeared more than one time per analysed group.

Statistical analysis

In this exploratory study design, a power calculation was not performed. In order to analyse the impact of a critical incident on gaze behaviour, the simulator states hypnotic given and beginning of anaphylaxis were subsumed to the group uneventful induction. The states mild, moderate, and severe anaphylaxis were subsumed to the group anaphylaxis. For analysis of the experience, the subjects were divided into two groups; Group A: resident doctors of first or second year; Group B: resident doctors of third, fourth, fifth year, staff, or senior anaesthetists. The group division cut-off at 2 yr of experience was based on the median experience level of our sample subject population.

Finally, the data were analysed by generalized estimation equations capable of dealing with correlated measurements within individuals. An exchangeable variance structure was chosen for the implementation of a linear model. The fraction of time spent for the fixation of ROI groupings (monitoring tasks, manual tasks, and other) within a session represented the dependent variable. Its relation to independent variables, given by a factor for ROI groupings and indicators for anaphylaxis and the experience groups, was assessed by main effects and interaction terms. The use of interactions permitted the evaluation of a possible influence that experience and the occurrence of an incident have on the frequency of ROIs and accordingly the distribution of VA. Results are represented by conditional means and 95% confidence intervals. All tests were conducted in an exploratory manner on a 5% level of significance. Further descriptive statistics are given by mean (so) for periods of time and absolute and relative frequencies for ROI occurrences. The computations were performed with the statistical software.
tool R 2.9.2 (R Foundation for Statistical Computing, Vienna, Austria) and PASW Statistics 18.0.2 (SPSS Inc., Chicago, IL, USA).

Results
A total of 15 anaesthetists participated in this study. Four of them were not available for the third session due to obligations in the operating theatre. The remaining 11 individuals (six males, five females) completed all three sessions, and only those were included in the analysis. In six of 22 data sets, the video data were not usable due to technical problems. Consequently, uneventful sessions and critical incident sessions of seven residents and additional uneventful sessions of two residents were analysed. The mean duration of trials was 579 (145) s in uneventful sessions and 884 (199) s in critical incident sessions. The mean analysis time was 14 (1) min per video minute. The most experienced participant had an anaesthesiological experience of 30 yr.

The spatial distribution of VA during different simulator states is given in Table 1. The ROIs with highest VA were the patient monitor, the patient’s thorax, the patient record (only before anaesthesia induction), or not classified. In the event of a critical incident, VA dedicated to the patient monitor increased from 20% to 30% ($P=0.003$). The anaesthetists looked at the anaesthesia chart as soon as the simulator recovered after the successful treatment of the anaphylaxis (indicating the documentation). Between 7.9% and 11.3% of the VA was dedicated to regions that were not covered by a specific ROI of the a priori classification (not classified).

In Table 2, the results of the multivariate analysis of the effects of a critical incident and the experience of the residents are given. When a critical incident occurred, the more experienced Group B was able to increase their VA dedicated to manual tasks from 21.2% to 24.9%, whereas in the inexperienced Group A, the VA decreased from 19.7% to 14.1% ($P=0.061$). At the same time, Group B maintained the amount of time dedicated to monitoring tasks and reduced the time dedicated to other than monitoring and manual tasks. In contrast, Group A increased VA related to monitoring tasks and other. In the analysis of the significance within subgroups, the impact of experience on VA tended to be more pronounced during critical incident sessions ($P=0.091$) than during uneventful sessions ($P=0.648$). Likewise, in the separate analysis of each group, the effect of the critical incident had more impact on the distribution between manual tasks, monitoring tasks, and other in Group A ($P<0.001$) than in Group B ($P=0.418$). However, a multivariate analysis of all factors and interaction terms defining the subgroups showed that there was not enough evidence in the data to provide statistical significance for the observed differences ($P=0.061$). Figure 2 shows the frequency of the ROIs and of the transitions between two ROIs for uneventful inductions and anaphylaxis. The less experienced cannot maintain the time dedicated to manual tasks during critical incidents.

Table 3 shows the five most frequent scan paths according to a previous definition. A clinically relevant scan path can be identified in Group B between the respiratory mask and the patient’s thorax which participants use for monitoring the efficiency of the mask ventilation. However, no single scan path including four different ROIs was identified among the most frequent ROI sequences.

Discussion
We used eye tracking to assess the distribution of VA in anaesthetists while inducing general anaesthesia. The majority of the time (89%) was dedicated to regions that
were covered by our classification of ROIs. In our setting, the most frequented ROI was the patient monitor with 21% in uneventful and 30% in incident states. In our study, participants spent a greater percentage of their fixation time on the patient monitor than the 5% reported earlier from covert observations in the real operation theatre. In that study, however, the maintenance phase of anaesthesia was investigated, which is less dynamic than the induction phase studied here. The time dedicated for monitoring and manual tasks in the present study are against the findings of a previous study that found 30% monitoring activity and 31% of manual tasks during simulated incidents. The increase in VA for the patient monitor during the critical incident suggests that the individuals actively directed their attention in order to have sufficient awareness of the situation. Moreover, these results imply that patient monitors play an important role for the maintenance of adequate SA while inducing anaesthesia.

Interestingly, during critical incidents, the more experienced anaesthetists tended to dedicate less time to monitoring and unrelated (other) tasks and to increase the time related to manual tasks when compared with the uneventful sessions. In contrast, the novice anaesthetists reacted inversely. There are some possible explanations for this finding: (i) the more experienced anaesthesia providers might be able to maintain sufficient SA without spending more time in monitoring tasks; (ii) they might have more spare capacity...
available and therefore can actively direct their attention towards manual tasks. However, these findings were not statistically significant.

We were surprised that the ROI sequence of respiratory mask–patient’s thorax–respiratory mask–patient’s thorax was the most frequent scan path only in the experienced group. In fact, we expected it to be a skill of comparable relevance in all levels of anaesthesia providers as it represents a basic technique that is applied in daily routine. Apparently, it is not. This finding merits further investigation and may be a training focus for anaesthesia novices.

The fact that all of the five most frequent scan paths included at least one ROI twice suggests that our definition of a scan path being as a recurrent sequence of four ROIs is not useful for the analysis of gaze behaviour in anaesthesia. For the detection of scan paths, the ROI patient monitor and the anaesthesia machine may have to be subdivided into more ROIs that each represents a single source of information ($\text{ETCO}_2$, heart rate, arterial pressure curve, etc.). Other ROIs in the present classification served mainly for visuo-motor processing and therefore, they should not be included in the search of scan paths. An anaesthesiological scan path may be defined as a recurrent, unintentional sequence of information-providing ROIs that appear if the subjects are faced with unexpected events (e.g. desaturation, hypotension, and other). In conclusion, the question of whether such scan paths exist remains unanswered until the methodological approach is refined.

Table 1  Distribution of VA for 23 ROIs sorted by group. The simulator condition includes the state pre-induction of all scenarios, the condition hypnotic given includes only the state hypnotic given of uneventful scenarios, the conditions anaphylaxis and recovery include the states beginning anaphylaxis (3)–severe anaphylaxis (6) and beginning of recovery (7)–complete recovery (8), respectively. The spatial distribution of VA is given in per cent for every simulator state (adds up to 100% per column); percentages above 10% are given in bold. *Missing values’ refers to fixations in which the ROI allocation was missed by the video observer.

<table>
<thead>
<tr>
<th>Regions of interest</th>
<th>Simulator condition</th>
<th>Pre-induction</th>
<th>Hypnotic given</th>
<th>Anaphylaxis</th>
<th>Recovery</th>
</tr>
</thead>
<tbody>
<tr>
<td>ROIs related to monitoring tasks 1  Patient record 26.29</td>
<td>2  Patient’s head 8.02</td>
<td>3  Nurse’s hands 6.07</td>
<td>4  Infusion 0.30</td>
<td>5  Anaesthesia machine 6.23</td>
<td>6  Patient’s thorax 11.50</td>
</tr>
<tr>
<td></td>
<td>7  I.V. line 1.18</td>
<td>8  Patient monitor 8.17</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ROIs related to manual tasks 9  Movement in room 0.24</td>
<td>10  Respiratory mask 5.58</td>
<td>11  Respiratory tubes 3.63</td>
<td>12  Patient’s mouth (intubation) 0.50</td>
<td>13  Adjusting anaesthesia machine 3.54</td>
<td>14  Placing i.v. line 0.00</td>
</tr>
<tr>
<td></td>
<td>15  Application of drugs 0.08</td>
<td>16  Anaesthesia trolley 3.86</td>
<td>17  Monitor cables 0.04</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other 18  Anaesthesia Chart 0.00</td>
<td>19  Nurse’s head 3.15</td>
<td>20  Surgical nurse’s head 0.05</td>
<td>21  Senior anaesthesiologist 0.00</td>
<td>22  Telephone 0.01</td>
<td>23  Not classified 11.07</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Missing values* 0.51</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2  Multivariate analysis of the effects of critical incident session (anaphylaxis vs uneventful induction) and of the experience (unexperienced Group A vs experienced Group B) on the temporal distribution of VA between manual and monitoring tasks and other. Given as means (95% confidence interval) of percentages.

<table>
<thead>
<tr>
<th>Group</th>
<th>Manual tasks</th>
<th>Monitoring tasks</th>
<th>Other</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uneventful induction A 19.7 (12.1–27.2)</td>
<td>70.4 (59.2–81.7)</td>
<td>9.8 (5.4–14.2)</td>
<td>0.061</td>
<td></td>
</tr>
<tr>
<td>Uneventful induction B 21.2 (14.3–28.1)</td>
<td>64.6 (56.3–73.0)</td>
<td>14.2 (5.5–22.9)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anaphylaxis A 14.1 (8.0–20.1)</td>
<td>72.5 (66.2–78.7)</td>
<td>13.4 (9.8–17.1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anaphylaxis B 24.9 (15.6–34.2)</td>
<td>65.9 (56.7–75.1)</td>
<td>9.2 (5.2–13.3)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
In view of the findings and the methodological knowledge of the present study, the methods for VA analysis have to be refined. For the investigation of the relation of VA and SA, a direct and objective assessment (e.g. Situation Awareness Global Assessment Technique, SAGAT) should be included into the analysis. It is more intrusive due to the required breaks during simulation but assesses all levels of SA separately (perception, comprehension, and projection). Therefore, it is preferable to the use of indirect indicators of SA such as performance (it is very hard to perform well without adequate SA).

The analysis of both VA and physiological data may result in insights into the mechanisms which are used by more expert anaesthesia providers to maintain sufficient SA in real and simulated scenarios with increased workload during critical incidents. Moreover, a scenario-specific definition of the main ROIs that provide the key information for a successful recognition and treatment of a critical event may be helpful and it would reduce the amount of data to be analysed.

Several facts limit the informative value of the study. Simulators are different to real settings, including qualitative differences such as missing skin colour changes. Carrying an eye tracker may introduce significant bias due to its intrusiveness even if the intrusiveness was rated low by the participants. Also in anticipation of a critical incident, attention and vigilance are heightened and may alter VA. The median of Group B was only 3 yr and can therefore not be defined as expert group. More experienced practitioners (senior anaesthetists) might produce different results. The study has an exploratory design and a low sample size; in six of 22, the video data were not usable due to technical reasons. Finally, the eye tracker captured only the visual aspect of spatial distribution of attention and is therefore not able to record other (e.g. haptic and acoustic) sources of information that are used for sufficient SA.

Simulated critical incidents have impact on the distribution of VA of anaesthetists. Furthermore, during the management of such incidents, the distribution of VA seems to be influenced by the experience of the anaesthetists. Further investigation in confirmatory designs is needed.

### Supplementary material

Supplementary material is available at British Journal of Anaesthesia online.

### Acknowledgements

We gratefully acknowledge the contribution of Klaus Bartl and Stefan Kohlbecher from the Institute of Clinical Neurosciences of the Ludwig-Maximilians University München for technical assistance with the EyeSeeCam as well as Thomas Villgrattner and Heinz Ulbrich from the Institute of Applied Mechanics of the Technische Universität München who provided the camera actuation mechanics. The simulator environment was provided by the Department of Anaesthesiology, Klinikum rechts der Isar, Technische Universität München.

---

**Table 3 Absolute numbers of the most frequent scan paths**

<table>
<thead>
<tr>
<th></th>
<th>Group A, uneventful inductions</th>
<th>Group B, uneventful inductions</th>
<th>Group A, anaphylaxis</th>
<th>Group B, anaphylaxis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of subjects</td>
<td>3</td>
<td>6</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Number of trials</td>
<td>6</td>
<td>10</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Mean duration of trial (s)</td>
<td>446</td>
<td>451</td>
<td>761</td>
<td>637</td>
</tr>
</tbody>
</table>

---

In view of the findings and the methodological knowledge of the present study, the methods for VA analysis have to be refined. For the investigation of the relation of VA and SA, a direct and objective assessment (e.g. Situation Awareness Global Assessment Technique, SAGAT) should be included into the analysis. It is more intrusive due to the required breaks during simulation but assesses all levels of SA separately (perception, comprehension, and projection). Therefore, it is preferable to the use of indirect indicators of SA such as performance (it is very hard to perform well without adequate SA).

The analysis of both VA and physiological data may result in insights into the mechanisms which are used by more expert anaesthesia providers to maintain sufficient SA in real and simulated scenarios with increased workload during critical incidents. Moreover, a scenario-specific definition of the main ROIs that provide the key information for a successful recognition and treatment of a critical event may be helpful and it would reduce the amount of data to be analysed.

Several facts limit the informative value of the study. Simulators are different to real settings, including qualitative differences such as missing skin colour changes. Carrying an eye tracker may introduce significant bias due to its intrusiveness even if the intrusiveness was rated low by the participants. Also in anticipation of a critical incident, attention and vigilance are heightened and may alter VA. The median of Group B was only 3 yr and can therefore not be defined as expert group. More experienced practitioners (senior anaesthetists) might produce different results. The study has an exploratory design and a low sample size; in six of 22, the video data were not usable due to technical reasons. Finally, the eye tracker captured only the visual aspect of spatial distribution of attention and is therefore not able to record other (e.g. haptic and acoustic) sources of information that are used for sufficient SA.

Simulated critical incidents have impact on the distribution of VA of anaesthetists. Furthermore, during the management of such incidents, the distribution of VA seems to be influenced by the experience of the anaesthetists. Further investigation in confirmatory designs is needed.

### Supplementary material

Supplementary material is available at British Journal of Anaesthesia online.

### Acknowledgements

We gratefully acknowledge the contribution of Klaus Bartl and Stefan Kohlbecher from the Institute of Clinical Neurosciences of the Ludwig-Maximilians University München for technical assistance with the EyeSeeCam as well as Thomas Villgrattner and Heinz Ulbrich from the Institute of Applied Mechanics of the Technische Universität München who provided the camera actuation mechanics. The simulator environment was provided by the Department of Anaesthesiology, Klinikum rechts der Isar, Technische Universität München.
Conflict of interest
None declared.

Funding
This project was supported by funds from the German Federal Ministry of Education and Research under the Grant code 01 EO 0901, by Bayerische Forschungstiftung (BFS: DOK-88-07), and in part within the DFG excellence initiative research cluster Cognition for Technical Systems (CoTeSys).

References
5 Bolstad CA, Cuevas HM. Integrating situation awareness assessment into test and evaluation. ITEA J 2010; 31: 240–6
9 Rivecourt M, de Kuperus MN, Post WJ, Mulder LJM. Cardiovascular and eye activity measures as indices for momentary changes in mental effort during simulated flight. Ergonomics 2008; 51: 1295–319
12 Brandt T, Glasauer S, Schneider E. A third eye for the surgeon. J Neural Neurosurg Psychiatry 2006; 77: 278