Anesthesia personnel's visual attention regarding patient monitoring in simulated routine and critical incidents. An eye-tracking study.

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Research Article

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Abstract

Background: Cognitive ergonomics design of patient monitoring may reduce human factor errors in high-stress environments. Eye-tracking is a suitable tool to gain insight into the visual interaction of healthcare professionals with patient monitors, which may facilitate their further development.

Methods: This prospective, randomized, high-fidelity simulation study compared anesthesia personnel's visual attention (fixation count and dwell time) to 15 areas of interest on the patient monitor during critical and non-critical anesthesia scenarios. Furthermore, we examined the extent to which participants' experience influenced visual attention and which vital signs displayed on the patient monitor received the most visual attention. We used mixed zero-inflated Poisson regression and mixed linear models to analyze the results.

Results: Analyzing 23 ten-minute scenarios, we found significantly more fixations to the areas of interest on the patient monitor during critical situations (rate ratio of 1.45; 95% CI 1.33 to 1.59; $p < 0.001$). However, the dwell-time on the areas of interest did not significantly differ between the critical and non-critical scenarios (coefficient of -1.667 ; 95% CI -4.549 to 1.229 ; $p = 0.27$). The professional experience did not significantly influence the visual attention (fixation: rate ratio of 0.88; 95% CI 0.54 to 1.43; $p = 0.61$ and dwell-time: coefficient of 0.889; 95% CI -1.465 to 3.229 ; $p = 0.27$). Regarding vital signs, anesthesia personnel paid the most attention to blood pressure (fixation: mean [SD] of 108 [74.83]; dwell-time: mean [SD] of 27 [15.90] seconds), end-expiratory carbon dioxide (fixation: mean [SD] of 59 [47.39]; dwell-time: mean [SD] of 30 [21.51] seconds), and the electrocardiogram (fixation: mean [SD] of 58 [64.70]; dwell-time: mean [SD] of 15 [14.95] seconds).

Conclusions: Critical anesthesia situations increased anesthesia personnel's visual interaction with the patient monitor. Furthermore, we found that their visual attention focused mainly on a few vital signs. To assist clinicians in critical situations, manufacturers should optimize monitors to convey necessary information as easily and quickly as possible and optimize the visibility of less frequently observed but equally critical vital signs, especially when they are in an abnormal range.

Background

Patient monitoring is an indispensable part of anesthesiologists' and intensivists' workplaces [1]. It provides relevant, critical information to the healthcare professionals at the point of care. However, anesthesia and intensive care are areas prone to human errors [2, 3]. Good cognitive-ergonomic design of monitoring devices improves situation awareness and significantly reduces human factor errors in high-stress environments [4, 5].

Exploring how healthcare providers interact with patient monitoring devices is necessary to further improve these technologies. Eye-tracking serves as a powerful tool for objectifying the visual interaction between users and their environment. In recent years, the available eye-tracking devices evolved considerably in terms of size, recording quality, and automated analysis capabilities. Mobile eye-tracking

devices have become established tools for gaining insights into cognitive processes such as visual attention, workload, confidence, and physician awareness [6–8]. Previous studies investigated the healthcare providers' visual attention regarding patient monitoring systems [8–11]. They found that during real anesthesia cases, healthcare professionals spent about 5% of their time observing the patient monitor [10]. The blood pressure and heart rate seemed to be the most frequently viewed vital signs during simulated anesthesia scenarios [11]. However, it is still highly debated whether emergencies or different levels of experience among healthcare providers change the visual attention span [10–14].

Using eye-tracking technology, this study investigated the visual attention (i.e., fixation count and dwell time) on the patient monitor during simulated anesthesia inductions with and without occurring critical incidents. We hypothesized that when managing an emergency situation, anesthesia personnel would pay more visual attention to the patient monitor than when dealing with a non-critical event. Furthermore, we investigated the influence of the participant's professional experience, and which vital signs received the most visual attention overall.

Methods

The Cantonal Ethics Committee of Zurich in Switzerland reviewed the study protocol and issued a declaration of no objection (Business Management System for Ethics Committees Number Req-2020-00059). We obtained written informed consent from all participants to use their data.

Study design

This investigator-initiated, prospective, single-center study investigated the visual attention regarding patient monitoring of anesthesia providers during simulated anesthesia inductions. We used eye-tracking data collected during a previously published high-fidelity simulation study [15]. The initial study compared an avatar-based visualization technology for patient monitoring with conventional, number- and waveform-based patient monitoring. We only examined the conventional, number- and waveform-based monitor modality with eye-tracking in the current study.

According to their availability, we recruited anesthesia teams that consisted of a nurse anesthetist and an anesthesiologist. Each team solved four different ten-minute scenarios. One of the scenarios was mild hypotension after induction without a critical incident. The three simulated emergencies were severe bronchospasm, malignant hyperthermia, and myocardial ischemia. Participants used a randomly determined monitoring modality in each scenario. When the teams performed scenarios with the conventional patient monitor, the randomly determined team leader wore a mobile eye-tracking device (Pupil Invisible by Pupil Labs, GmbH, Berlin, Germany) while managing the scenarios. We used Research Randomizer Version 4.0 (<http://www.randomizer.org>) to randomize the team leader, the monitoring modality used in the scenario, and the scenario sequence.

Simulation environment and equipment

We conducted the simulations in a backup operating room that mirrored the study center's active operating rooms. In addition, we used a state-of-the-art, full human patient simulator (HAL S3201, Gaumard Scientific Company, Inc., Miami, FL, USA) and real medications and airway management tools to increase simulation fidelity. The anesthesia teams used a Philips IntelliVue MX500 (Koninklijke Philips N.V., Netherlands) patient monitor configured to resemble the study center's regular MX550 and MX800 monitors closely. We tagged the patient monitor in the simulation environment using pre-generated quick response (QR) code, which enables automatic detection by the Pupil Player software (Pupil Labs, GmbH, Berlin, Germany), a prerequisite for automated processing.

Data collection

Before beginning the scenario, we calibrated the eye-tracking device to the participant. Then, we recorded the participant's field of view as a video feed using Pupil Invisible (Pupil Labs, GmbH, Berlin, Germany), the mobile eye-tracking device. The device was connected to a cell phone that participants carried in their pocket and served as a power source and storage unit. At the end of each scenario, we uploaded the eye-tracking data to a research server and made backup copies on physical hard drives.

Then, we manually checked the eye-tracking data's quality and cut the videos to the beginning and end of the 10-minute simulation. We then started the post hoc semi-automated video analysis using Pupil Labs proprietary software Pupil Player (Pupil Labs, GmbH, Berlin, Germany) on an Acer Aspire V15 Nitro laptop (Acer Inc., New Taipei City, Taiwan). Using mentioned software, we traced the patient monitor using the surface Tracker plugin, which automatically detects QR codes in the video sequence. Then we defined 15 areas of interest on the patient monitor screen (Fig. 1). The Fixation Detector plugin enabled us to automatically export all fixations and their durations (dwell time) on the areas of interest as Microsoft Excel spreadsheets (Microsoft Corporation, Redmond, USA). During the post hoc video analyses, we stopped each recording five times to verify the accuracy of the boundaries of the areas of interest. In case we noticed incorrect boundaries during the recording, we manually corrected the deviation.

Outcomes

The primary outcome measure was the number of fixations per area of interest. We counted a fixation if participants held their gaze for more than 100 milliseconds on a single location inside an area of interest. We defined the secondary outcome as dwell-time, i.e., the accumulated time spent on an area of interest.

Statistical analysis

We only included scenarios in which participants used conventional monitoring as this display modality represents the current state of the art method. Regarding the professional experience of anesthesia providers, we considered trainees as participants with less than five years and experts as ones with more than five years of clinical experience. We defined the case with mild hypotension after induction as a non-critical scenario and the three other simulations (bronchospasm, malignant hyperthermia, and myocardial ischemia) as critical ones.

For descriptive statistics, we provide means and standard deviations (SD) as well as medians and interquartile ranges (IQR) for continuous data and numbers and percentages for categorical data. To compare the visual attention (fixations and dwell-times) on the areas of interest in critical and non-critical scenarios and the visual attention of trainee and expert team leaders, we used mixed models with random intercept per team to incorporate the fact that measurements from the same team are not independent. In detail, for the outcome fixation count, we used mixed zero-inflated Poisson regression models. Regarding the dwell-time, we applied mixed linear models. All models included both the binary experience variable and the binary criticality variable. In the logistic regression part of the mixed zero-inflated Poisson model, we included a scenario variable. This variable accounts for the fact that not every area of interest (vital sign) had the same importance in each scenario. For example, the electrocardiogram is necessary to diagnose the ST-segment elevations in the myocardial ischemia scenario. In contrast, vital signs that affect ventilation are more important in severe bronchospasm scenario. All statistical analyses were performed using R version 3.6.2 (R Foundation for Statistical Computing, Vienna, Austria). We used Prism 8 (GraphPad Software Inc., California, USA) to create all figures. We considered a p-value of less than 0.05 to determine statistical significance.

Results

This study was conducted in May 2020, including 52 anesthesia teams. Each team performed two scenarios with conventional patient monitoring. We excluded 16 teams as the eye-tracking setup was revised because the laminated QR codes used reflected and were not detected by the eye-tracking software. In addition, we had to exclude another 16 teams because the video material was recorded incompletely due to technical issues. Of the remaining 20 teams that performed 40 scenarios with conventional patient monitoring, we excluded 17 scenarios due to inaccuracies in eye-tracking calibration (e.g., alternate squinting or prescribed glasses). Thus, we analyzed 23 ten-minute simulations performed with conventional patient monitoring. In each simulation, we analyzed 15 areas of interest of the patient monitor (Fig. 1). Figure 2 shows the exclusion criteria in detail. Table 1 displays further study and participants' characteristics.

Table 1

Study and participants characteristics. We considered anesthesia providers with less than five years of professional experience as trainees and anesthesia providers with more than five years of professional experience as experts.

Study characteristics	
Simulations conducted with conventional patient monitor and analyzed with eye-tracking, <i>N</i>	23
Analyzed non-critical scenarios	4 of 23 (17%)
Analyzed critical scenarios	19 of 23 (83%)
Analyzed areas of interest on the patient monitor	15
Participant's characteristics	
Team leader, <i>N</i>	20
Sex, female	11 of 20 (55%)
Job position	
Anesthesia nurse	12 of 20 (60%)
Anesthesiologist	8 of 20 (40%)
Experience level	
Trainee	11 of 20 (55%)
Expert	9 of 20 (45%)

Overall visual attention on the patient monitor

Within all analyzed simulations, participants had a mean (SD) of 423 (257) fixations per scenario and a mean (SD) dwell time of 184 (52) seconds on the patient monitor (sum of all fixations/ dwell times of all 15 areas of interest on the patient monitor). This accounts for 30.7% (184 of 600 seconds) of the simulation time.

Visual attention to areas of interest in non-critical and critical simulations

Regarding the degree of criticality, we found that anesthesia providers had a mean (SD) of 14 (16) fixations with a mean (SD) dwell-time of 11.1 (12.6) seconds per area of interest during non-critical simulations compared to a mean (SD) of 24 (38) fixations with a mean (SD) dwell-time of 9.4 (10.1) seconds during critical ones. Comparison of fixations using zero-inflated Poisson models yielded a rate

ratio of 1.45 (95% CI 1.33 to 1.59; $p < 0.001$), meaning participants had about 45% more fixations on the areas of interest in the critical than in the non-critical scenarios. The analysis for dwell-time showed a coefficient of - 1.67 seconds (95% CI - 4.55 to 1.23 seconds; $p = 0.27$). This means that the time spent looking at the areas of interest on the monitor was 1.6 seconds shorter for critical than for non-critical scenarios. However, this result was not significant.

Visual attention to areas of interest and professional experience

Regarding the participants' professional experience, trainees had a mean (SD) of 23 (35) fixations with a mean (SD) dwell time of 9.3 (10.1) seconds per area of interest. Experts had 22 (35) fixations with a dwell-time of 10.3 (11.8) seconds per area of interest. Comparing trainees' and experts' fixation count, zero-inflated Poisson models yielded a rate ratio of 0.88 (95% CI 0.54 to 1.43; $p = 0.61$), indicating no evidence for a difference in number of fixations of experts and trainees on the areas of interest. Analyzing the dwell-time, we found a coefficient of 0.89 seconds (95% CI - 1.47 to 3.23 seconds; $p = 0.27$), which means that experts spent a similar time on the areas of interest than trainees.

Vital Signs

Within all simulations analyzed, participants paid the most visual attention to blood pressure (fixation: mean [SD] of 108 [74.83]; dwell-time: mean [SD] of 27 [15.90] seconds), end-expiratory carbon dioxide (fixation: mean [SD] of 59 [47.39]; dwell-time: mean [SD] of 30 [21.51] seconds), and the electrocardiogram (fixation: mean [SD] of 58 [64.70]; dwell-time: mean [SD] of 15 [14.95] seconds). Figure 3 displays the fixation count and dwell-time of all analyzed areas of interest as boxplots.

Discussion

By using eye-tracking technology we found that anesthesia providers observed the patient monitor for about 31% of the simulation time, with an increase in monitor fixations of approximately 45% during critical situations. However, dwell time did not differ significantly when comparing critical and non-critical scenarios. Further, the participants' different professional experiences did not significantly affect the distribution of visual attention. The vital signs, blood pressure, end-expiratory carbon dioxide, and electrocardiogram received the most visual attention.

During critical anesthesia events, the staff actively increased their number of fixations on the patient monitor to gain sufficient awareness of the situation. However, despite more fixations during such events, we did not find a significant increase in dwell time. This seems somewhat counterintuitive but may be explained by a different use of the patient monitor in the care of stable and unstable patients. We believe that in volatile critical events, rapid vital sign changes require more but shorter fixations on the patient monitor to maintain good situational awareness and manage the events successfully. In the case of a hemodynamically unstable patient, the anesthesiologist must recognize the problem within seconds, understand the meaning or severity of the problem, realize where the situation will go, develop a therapy

concept, and implement this concept immediately. Then, the anesthesiologist must check the applied therapy for success and continuously reevaluate the patient to maintain situation awareness [16, 17]. These stressful situations with tremendous time pressure may lead to more frequent but shorter fixations of the corresponding vital signs on the patient monitor and may explain the findings of this study.

In our analyses, the professional experience level did not affect the fixation count and dwell-time on the patient monitor. Literature provides conflicting results on this topic. Schulz et al. postulated a tendency for more experienced anesthesiologists to devote less time to the patient monitor during critical incidents [12]. On the contrary and consistent with our results, in a more recent study by Grundgeiger et al., the professional experience level did not affect the monitoring-related visual attention in simulated and real anesthesia cases [10]. Nevertheless, there may be different main reasons why anesthesia personnel fixate the patient monitor during critical incidents. Inexperienced anesthesia providers may mainly check the monitor to get an idea of the situation at hand, while experienced personnel may correctly perceive the situation at hand more quickly, but still often fixate the monitor to anticipate the future course. Further studies are needed to investigate this hypothesis.

During our simulations, anesthesia providers looked at the patient monitor approximately 31% of the time. This proportion is similar to other simulation studies [12, 18] but drastically different from observed visual attention in the real operating room [10, 14]. Studies reported dwell-times on the patient monitor during real surgery to be approximately 5% [10, 14]. However, these studies included the intraoperative anesthesia maintenance phase, which is less dynamic than the anesthesia inductions investigated in our study.

Analyzing the areas of interest on the patient monitor, we found that the vital sign blood pressure received the most visual attention in both non-critical and critical scenarios. This is consistent with a recent study [11]. However, we expected the respiratory vital signs such as oxygen saturation, tidal volume, and respiratory rate to receive more visual attention. This may be explained by the additional sonification used in monitoring the oxygen saturation. The modulating pitch of the heart rate sound reliably indicates oxygen saturation [19]. Our study suggests that the auditory input in monitoring oxygen saturation is sufficiently reliable to the anesthesia experts that they do not double-check this visually. Further intelligent sonification of vital signs could be helpful and is already investigated [20, 21].

This study has several limitations. First, we had to exclude more than half of the teams from the analyses due to technical issues or poor data quality. In particular, calibration of the eye-tracker for ocular pathologies (e.g., alternate strabismus or wearing prescription glasses) was not feasible. This shows that despite the massive development of eye-tracking hardware and software in recent years, the technology is still error-prone, and it is difficult to obtain high-quality video recordings, which are essential for reliable and semi-automated analyses. Second, we conducted this study in a tertiary care hospital in central Europe. Results may vary under different conditions and in other parts of the world. Third, all simulations inherently entail a bias. They may not reflect the actual critical incident's psychological and temporal pressures and dynamics. Interestingly, a recent study has reproduced results from a randomized control

trial in a simulation study [22]. Hence, this may question the importance of simulation bias. However, this study possesses several strengths. First, we reduced selection bias by balancing participant selection and randomizing the scenario sequence. We sought to address the inherent limitation of authenticity that resonates with all simulation-based studies [23] through our in situ study design and efforts to represent clinical reality as closely as possible. Further, we used eye-tracking hardware that was no more intrusive than wearing regular glasses to produce high-quality video footage. Finally, we replaced error-prone human analysis with semi-automated analysis to help ensure high-quality data.

Conclusion

Critical situations increased anesthesia professionals' visual attention to the patient monitor. The anesthesia personnel mainly visually focused on blood pressure, end-expiratory carbon dioxide value, and electrocardiogram. We advise patient monitor manufacturers to best match the medical professionals' needs to optimize information transfer. Furthermore, we believe that the visibility of less frequently observed but equally critical vital signs should be improved, especially when they are in an abnormal range.

Abbreviations

IQR
Interquartile range
SD
Standard deviation

Declarations

Ethics approval and consent to participate

The study was conducted at University Hospital Zurich in Zurich, Switzerland in May 2020. Peter Kleist of the Cantonal Ethics Committee of the Canton of Zurich in Switzerland, reviewed the study protocol and issued a declaration of no objection (Business Management System for Ethics Committees Number Req-2020-00059). We obtained written informed consent from all participants. All methods were performed in accordance with the relevant guidelines and regulations.

Consent for publication

We obtained written informed consent from all participants for the use of their data for publication.

Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests

DWT and CBN are designated inventors of Visual Patient technology, for which the University of Zurich holds various patents and trademarks. There are cooperation and licensing agreements with Philips Medizin Systeme Böblingen GmbH, Böblingen, Germany; Koninklijke Philips NV, Amsterdam, The Netherlands; and Philips Research/Philips Electronics Nederland BV, Eindhoven, The Netherlands. Under these agreements, DWT and CBN may receive royalties. DWT, CBN, and DRS are designated inventors of Visual Clot technology, for which the University of Zurich holds various patents and trademarks. The University of Zurich signed a letter of intent for cooperation and licensing agreement with Instrumentation Laboratory Company/Werfen Corporation, Bedford, MA, USA, and Barcelona, Spain. Under this and future agreements, they may receive royalties. DWT, CBN, and DRS received travel support for consulting Instrumentation Laboratory, Bedford, MA, USA.

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Authorship Contributions

TRR, EJCM, SS, JB, CM, CBN, DRS and DWT made substantial contribution to conception and design, acquisition of data, or analysis and interpretation of data; TRR, EJCM, SS, JB, CM, CBN, DRS and DWT helped drafting the article or revising it critically for important intellectual content; TRR, EJCM, SS, JB, CM, CBN, DRS and DWT gave final approval of the version to be published; and TRR, EJCM, SS, JB, CM, CBN, DRS and DWT agreed to be accountable for all aspects of the work thereby ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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Figures

Figure 1

Conventional monitor configuration investigated with eye-tracking in this study. White numbered boxes indicate the predefined areas of interest. 1: Time; 2: electrocardiogram (ECG); 3: heart rate (HR); 4: oxygen saturation (SpO₂); 5: ST-analysis of electrocardiogram (ST-Analysis); 6: central venous pressure (CVP); 7: Arterial blood pressure (ABP); 8: end-tidal carbon dioxide concentration (etCO₂); 9: respiratory rate (RR); 10: tidal volume (TV); 11: temperature (Temp); 12 bispectral index (BIS); 13: train of four peripheral nerve stimulation (TOF); 14: Button for alarm acknowledgment; 15: Patient monitor settings (PM).

Figure 2

Study setup and exclusion criteria. We changed the QR codes because they were reflective and could not be read by the eye-tracking software. Technical issues were low battery capacity of the eye-tracking device, lack of storage space, an unstable connection between eye tracker and storage device, and problems uploading to the Pupil Player Cloud. The 20 teams that remained after exclusion performed 40 simulations with conventional patient monitoring. After a manual quality check, we excluded 17 scenarios due to eye-tracking calibration inaccuracies (e.g., alternate squinting or prescribed glasses).

Figure 3

Fixation counts (**A**) and dwell-time (**B**) for all areas of interest in all analyzed scenarios. Box plots are medians with interquartile ranges. Whiskers are 95% confidence intervals. ABP = Arterial blood pressure; etCO2 = end-tidal carbon dioxide concentration; ECG = electrocardiogram; PM settings = Patient monitor settings; SpO2 = oxygen saturation; HR = heart rate; BIS = bispectral index; TOF = train of four peripheral nerve stimulation; ST-Analysis = ST-analysis of electrocardiogram; CVP = central venous pressure; Time = Time display on patient monitor; 12-Lead ECG = 12-lead electrocardiogram; RR = respiratory rate; TV =

tidal volume; Temp = temperature; Acknowledge alarm = Button for alarm acknowledgment; Anesthesia providers n = 20, Simulations analyzed n = 23