

RESEARCH

Open Access



Anaesthesia professionals' perspectives on ECG interpretation and arrhythmia situation awareness with Visual Patient Heart: a qualitative multicentre study

Max Ebensperger^{1†}, Cynthia A. Hunn^{2†}, Tadzio R. Roche², Arend Rahrisch², Achilles Delis³, Florian Piekarski³, Florian J. Raimann⁴, Sayeh Bagheri⁵, Svenja Letz¹, Gregor Massoth³, Kai Zacharowski⁴ and David W. Tscholl^{2*}

Abstract

Background The Visual Patient Avatar concept transforms conventional patient monitoring data into a dynamic, animated representation of the patient, enhancing situation awareness of vital signs and measurement status. Rapid recognition and response to cardiac pathologies are critical in anaesthesia and critical care. Visual Patient Heart (VPH) integrates cardiac data from the Philips "ST/AR algorithm", a feature in Philips patient monitors, into visual design elements inside the heart element of the Visual Patient Avatar, specifically aiming to improve situation awareness of arrhythmias and ST-segment deviations.

Methods Participants evaluated a randomized series of 12-lead ECGs alongside corresponding VPH visualizations, each shown briefly to assess the speed of information transfer. Immediately after the exercise, they were asked two open-ended questions and encouraged to speak freely about perceived advantages and areas for improvement of the VPH concept. Their verbal responses were transcribed through field notes and analyzed using a template-guided analysis. The analysis of correct responses in the ECG-avatar comparison test is reported separately in a dedicated paper.

Results Analysis of 193 statements from 41 participants revealed that participants perceived VPH as intuitive, easy to learn, and cognitively less demanding than conventional ECG interpretation. Benefits reported by participants included improved situation awareness, faster rhythm recognition, and increased decision confidence. Suggestions for improvement addressed visual clarity, the need for more training, and integration with conventional ECG data. Concerns included over-reliance on the system and potential erosion of traditional ECG interpretation skills.

Conclusion The VPH system was well received, with participants highlighting its simplicity, clarity, and potential to enhance situation awareness. Feedback also raised important considerations around explainability, trust, and

[†]Max Ebensperger and Cynthia A. Hunn contributed equally to this work.

*Correspondence:
David W. Tscholl
david.tscholl@usz.ch

Full list of author information is available at the end of the article



© The Author(s) 2026. **Open Access** This article is licensed under a Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License, which permits any non-commercial use, sharing, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if you modified the licensed material. You do not have permission under this licence to share adapted material derived from this article or parts of it. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit <http://creativecommons.org/licenses/by-nc-nd/4.0/>.

integration of the visuals with conventional ECGs. These findings support further development and evaluation in more complex, clinically realistic settings.

Keywords Diagnosis, Patient monitoring, Situation awareness, Visual Patient Avatar, Qualitative research

Introduction

Background

Technological advancements in patient monitoring have greatly enhanced the quality and safety of patient care, particularly in perioperative [1, 2] and critical care settings [3]. Traditionally, vital signs have been displayed as numerical values or waveforms, each representing a single measurement from a single sensor [4]. This single-sensor-single-indicator format requires clinicians to mentally integrate multiple data streams in real time to form a coherent clinical picture of the patient's situation. Such piecemeal data gathering may increase clinicians' cognitive load [5]. Up to 80% of anaesthesia and critical care treatment errors are associated with poor situation awareness [6–8]. Cognitive psychology suggests the human brain processes visual elements more efficiently than abstract data [9, 10]. In response, user-centered monitoring solutions have been developed to reduce cognitive effort and enhance clinical performance [11]. One such innovation is the Visual Patient concept, developed at the University Hospital Zurich, Switzerland, and commercially available as the *Philips Visual Patient Avatar*. This system converts vital sign data into an animated avatar that visually represents real-time physiological changes [12–14]. Cardiac events such as arrhythmias or myocardial ischemia remain among the most critical complications in anaesthesia and intensive care, requiring rapid and accurate detection to guide timely intervention [15, 16]. Interpretation of the conventional 12-lead ECG is the gold standard for cardiac diagnosis, but it is also cognitively demanding and time-intensive, particularly in acute settings. The Philips “*ST/AR algorithm*” supports clinicians by automating ECG waveform analysis, detecting arrhythmias in single-lead traces and ischemic changes across multiple leads [17, 18]. The Visual Patient Heart (VPH) concept, an extension of the Visual Patient Avatar system, integrates the “*ST/AR algorithm*” output into the animated avatar's heart visualization, providing a real-time visual representation of cardiac pathology. As with the original Visual Patient, we developed VPH based on principles of situation-awareness-oriented design, aiming to convey goal-relevant information as quickly as possible and with minimal cognitive effort [19]. Originally developed in aviation, these principles are increasingly applied in anaesthesia and intensive care [8]. User-centered, situation-awareness-oriented designs aim to present key patient data clearly, minimizing cognitive load and supporting rapid decision-making [20]. The VPH leverages this approach by providing direct visual

representations of cardiac activity to help clinicians detect events, such as suspected myocardial ischemia, that may require a subsequent 12-lead ECG for confirmatory diagnosis.

Objectives

This study evaluated anaesthesia providers' perceptions of the VPH concept after exposure to standardized and randomized simulated scenarios, comparing VPH with conventional 12-lead ECG displays. In this study, we qualitatively analyzed participant feedback using reflective thematic analysis to identify perceived advantages and potential areas for improvement.

Methods

Ethics approval and consent to participate

Informed consent was obtained from all participants, and all responses were anonymized to ensure confidentiality. The study received a declaration of non-jurisdiction from the Cantonal Ethics Commission of the Canton of Zurich, Switzerland (BASEC No.: Req-2024-00353), as it did not fall within the scope of the Swiss Human Research Act. All participating centers in Germany obtained ethical approval from their respective local ethics committees: Ethics Committee of the Faculty of Medicine, University of Bonn (AZ 2024-209-BO), Ethics Committee of the Medical Faculty, Goethe University Frankfurt (#2024–1760), and Ethics Committee of the School of Medicine, Technical University of Munich (2024-383-S-CB).

Study design

We conducted a multicenter qualitative study with participants recruited from three tertiary care institutions in Germany: the University Hospital of Bonn (UKB), the University Hospital of Frankfurt (UKF), and the TUM University Hospital Munich (TUM). Data collection was performed between July and November 2024. This qualitative study was conducted following a preceding quantitative experiment using the same participant cohort, in which participants were exposed to simulated clinical scenarios comparing the Visual Patient Heart (VPH) with conventional 12-lead ECG displays. The qualitative component aimed to capture participants' perceptions, interpretations, and experiences after interacting with both visualization modalities. A study facilitator captured verbal responses as contemporaneous field notes, including verbatim phrases when possible. After documentation, each statement was read back to the participant to

confirm its accuracy in meaning and content. This procedure was applied consistently across all participating centers and for every individual statement. If a response was misinterpreted, participants could immediately correct or clarify it. Individual participants could contribute multiple statements, each of which was coded separately. To minimize social desirability bias, participation was voluntary, organized locally, and conducted during working hours, with no consequences for participants' responses. Data were accessible only to the co-authors and were fully anonymized prior to coding. Non-identifying contextual information (e.g., role, center, prior experience, gender, ECG experience, and self-reported skill level) was collected, stored, and analyzed separately from the statements. The full statements are available in Supplementary Material 1.

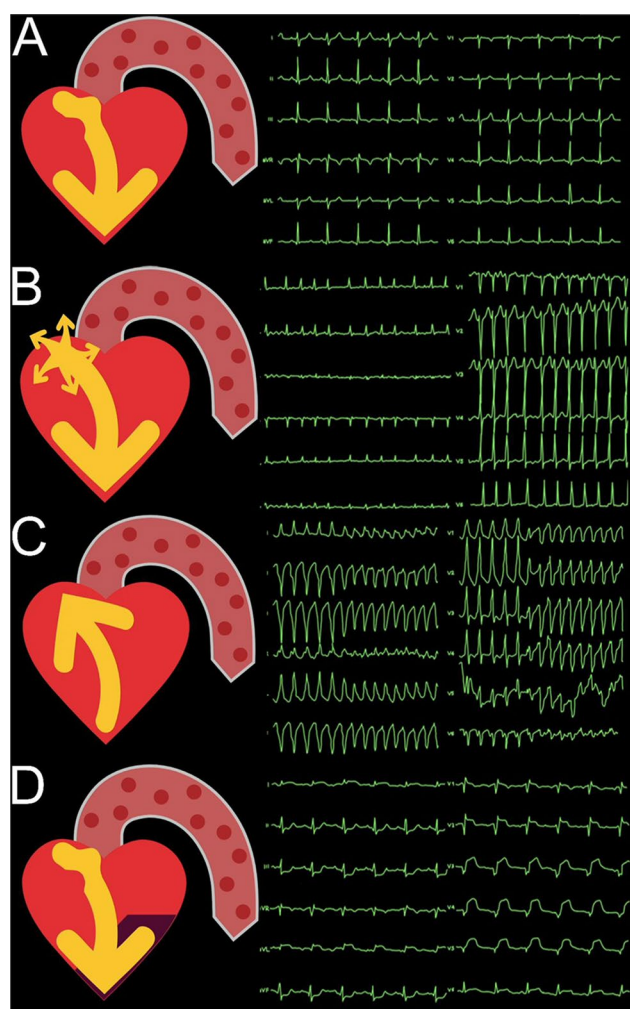


Fig. 1 Four examples showing 12-lead ECG visualisations next to corresponding VPH designs. **A** Sinus Rhythm. **B** Atrial Fibrillation. **C** Ventricular Tachycardia. **D** STEMI anterior

Visual Patient Heart

The Visual Patient Heart (VPH) is a prototype and is not yet commercially available. It represents an extension of the Philips Visual Patient Avatar, which currently provides a simplified cardiac visualization indicating heart rate (fast/moderate/slow) and ST-segment abnormalities (anterior/posterior/inferior/multiple), as shown in Supplementary Material 2. The VPH expands this approach by introducing 11 additional visualizations to represent a broader range of cardiac pathologies within the same intuitive, avatar-based visualization system. Importantly, while developed as an extension of the Visual Patient Avatar, the VPH concept can also function as a stand-alone visualization independent of the full avatar system. In the preceding quantitative experiment, participants were exposed to simulated clinical scenarios representing 11 cardiac states [21]. Each scenario was presented for six seconds, using either the VPH or a conventional 12-lead ECG display. Prior to the experiment, participants viewed a standardized training video (Supplementary Video 1) introducing VPH visualizations and were familiarized with the layout of the conventional ECG simulations, which followed standard clinical formats. The six-second exposure time was chosen to simulate sudden physiological changes and arrhythmia onset, as encountered in emergency, critical care, or intraoperative settings requiring rapid decision-making. This design emphasizes situation awareness rather than detailed ECG interpretation, which remains the diagnostic gold standard. Figure 1 illustrates representative examples of both visualization modalities used in the experiment (standard 12-lead ECG and VPH).

Participant survey and thematic analysis

Participants were asked to respond to two open-ended questions designed to capture spontaneous perceptions of the strengths and limitations of the VPH concept. They were encouraged to express their views freely without constraints. German responses were translated into English using ChatGPT-4 (OpenAI, San Francisco, CA, USA). All translations were reviewed and verified by authors with native-level proficiency in both German and English to ensure semantic accuracy and minimize translation bias. Any discrepancies or ambiguities were resolved through consensus among the authors.

Thematic analysis was conducted using an inductive approach. Authors DWT and AR developed the initial coding template through iterative familiarization with the data and identification of emerging patterns [22]. The resulting coding template is presented in Fig. 2. Six authors (ME, CAH, TRR, AR, AB, DWT) independently applied the coding template to the translated statements. Recurring patterns were continuously evaluated, and the coding framework was iteratively refined throughout the



Fig. 2 Coding templates for structured feedback by the participants. **A** Question 1: What Advantages Do You See in Using Visual Patient Heart? **B** Question 2: Where Do You See Weaknesses or Areas for Improvement in the Technology?

analysis. Each statement was defined as a single, coherent sentence. Individual participants could contribute multiple statements, each of which was coded separately. If the investigators disagreed after multiple rounds of statement coding, the final decision was made in a joint discussion. All co-authors reviewed and approved the final coding decisions. Statements were assigned to major themes and subthemes through an iterative coding process.

Data management

Data management was performed using Microsoft Word and Excel 365 (Microsoft Corporation, Redmond, WA, USA). To support transparency of the findings, we report the number and proportion of statements relative to the total dataset and across identified major themes. These quantitative summaries are provided for descriptive purposes only and are not intended as statistical inference. Figures were created using Microsoft PowerPoint 365 and draw.io Version 27.1.4 (Seibert Media GmbH, Wiesbaden, Germany).

Study participants and survey

Of the 75 participants participating in the preceding quantitative experiment, 41 participated in the survey. Participants represented a range of professional roles and experience levels, including resident anaesthesiologists, attending anaesthesiologists, and nurse anaesthetists. All participants were clinically active

anaesthesia professionals who spent the majority of their clinical working time in operating theatres and were routinely exposed to standard patient monitoring. Demographic details are provided in Table 1.

The survey began with two open-ended questions:

1. What advantages do you see in using Visual Patient Heart?
2. Where do you see weaknesses or areas for improvement in the technology?

These questions were embedded in a brief interview guide used to standardize data collection across participants and study sites. The guide was intentionally minimalist and designed to facilitate open, unconstrained responses rather than to structure an in-depth qualitative interview. This approach has been applied in several prior studies by our group to elicit broad, unprompted feedback [12, 23, 24]. An English-language version of the interview guide is provided in Supplementary Material 2.

Reflexivity

As authors, we represent the fields of anaesthesiology and cardiology and span different career stages, with shared experience in the design, conduct, and analysis of qualitative research. Our professional backgrounds and roles inevitably informed our perspectives and analytic focus. Throughout the study, we engaged in ongoing interdisciplinary discussions to reflect on and refine our assumptions and to incorporate diverse viewpoints into the interpretation of the findings. CAH, TRR, AR, and DWT conducted interviews at the centers. The distribution by site was as follows: UKF (TRR, CAH), UKB (AR, TRR, DWT), and TUM (CAH, TRR, DWT). Among the authors, ME, CAH, and AR are residents in anaesthesiology; TRR, AD, FP, FJR, SL, GM, and DWT are attending anaesthesiologists; SB is a resident in cardiology; and KZ is the director of an institute of anaesthesiology, critical care medicine, and pain therapy.

Results

Qualitative analysis

A total of 193 statements were extracted from the field notes for qualitative analysis. Participants contributed more responses to the first question regarding the perceived advantages of VPH (127 out of 193 statements, 66%) than to the second question concerning areas for improvement (66 out of 193 statements, 34%). Figure 2 presents the coding templates depicting the topics identified for each of the two interview questions. Complementing this, Tables 2 and 3 provide an overview of the major themes, their corresponding subthemes, frequencies, and representative participant statements. All 193 statements are presented in full in Supplementary

Table 1 Participant characteristics in detail (n = 41)

Centers	Participants
UKF (%)	19 (46%)
TUM (%)	15 (37%)
UKB (%)	7 (17%)
Age	Years
Mean (SD)	35.6 (9.8)
Median [Min, Max]	33 [22, 60]
Gender	
Male (%)	17 (41.5%)
Female (%)	24 (58.5%)
Job	Participants
Nurse (%)	15 (36.5%)
Resident (%)	16 (39%)
Specialist (%)	10 (24.5%)
Experience	Years
Mean (SD)	9.3 (9.9)
Median [Min, Max]	6 [0, 38]
ECG / week	
Mean (SD)	26.5 (49.2)
Median [Min, Max]	10 [0, 300]
Skill	(0-100 scale)
Mean (SD)	45.7 (25.8)
Median [Min, Max]	50 [0, 86]

Abbreviations: UKF: University Hospital of Frankfurt am Main, TUM: Technical University Hospital of Munich, UKB: University Hospital of Bonn

Table 2 Major themes and subthemes, including counts, percentages, and illustrative examples. Question 1: What Advantages Do You See in Using Visual Patient Heart?

Perceived Benefits (7/127 [6%] subtotal 44/127 [35%])	"Heart rhythms fit well with it" UKB, nurse"During the study, I realized that adding more details makes the system better and would effectively help more in everyday use"UKB, physician"Good as a complementary tool" TUM, physician
Improved Awareness (9/127 [7%])	"Quickly noticed, especially with more complex pathologies" UKF, physician "Faster recognition from a distance, practical e.g., during room changes or distractions" UKF, physician" Visually, rhythms are easier to grasp" TUM, nurse
Increased Decision Confidence (9/127 [7%])	"Faster visual diagnosis, practical" UKF, physician "Some things are more obvious and recognized faster" UKF, physician "Effective with clearly different frequencies" UKF, nurse
Time Savings (14/127 [11%])	"State becomes recognizable faster once you're familiar with the visualization" UKF, nurse"Fast, easy" UKF, nurse
Reduced Workload (5/127 [4%])	"Easier to recognize certain rhythms" TUM, nurse" Less stress in a short amount of time "TUM, physician
User-Friendliness (10/127 [8%] subtotal 53/127 [42%])	"Intuitive" TUM, nurse "Easy to understand" UKB, physician" Animations are easy to understand" UKF, nurse
Quick and Easy Learnability (11/127 [9%])	"Easy to learn" TUM, nurse" Does not necessarily require an introduction" UKF, physician" With more time/training, it could be well memorized" UKF, physician
Understandability Across Experience Levels (12/127 [9%])	"Good for beginners as it visualizes where it's coming from and going to; if it's backward, something is wrong" UKB, physician" Helpful for those with little practice as a nursing assistant" UKF, physician
Design Efficiency (15/127 [12%])	"Visualizations are easy to remember, and rhythms are easy to recognize" UKF, physician "Very clear, no need to look at 1,000 leads" UKF, nurse" Complex content simplified to basics" UKF, physician
Aesthetic Appeal (5/127 [4%])	"Well presented" UKB, physician
Feedback On Specific Visualizations (1/127 [1%] subtotal 18/127 [15%])	"Pulsation is good" TUM, physician
ST-Segment (7/127 [6%])	"Simple visualization, e.g., ST segments are intuitive and assignable" UKB, physician
Atrial Visualizations (3/127 [2%])	"Sinus rhythm node is good" UKF, physician
Ventricular Visualizations (1/127 [1%])	"Bigeminy and trigeminy patterns" UKF, nurse
Pacemaker (6/127 [5%])	"Extras like pacemaker leads are cool" TUM, physician
Potential Use-Cases (3/127 [2%])	"Clearly visible from a distance" UKB, nurse
Non-specific Positive Feedback (9/127 [7%])	"Find it cute" TUM, physician "More impactful" TUM, nurse

Material 1. The following section provides a detailed overview of the topics that emerged from the responses.

Question 1: What advantages do you see in using VPH?

Perceived benefits

One participant described the VPH visuals as “more tangible than a 12-lead ECG (UKF, nurse),” suggesting a more intuitive or accessible presentation of cardiac information. Another noted that it was “better than just a single lead or a still image of a single-lead ECG (UKB, physician),” suggesting a perceived improvement over standard patient monitors, which often show only two ECG waveforms. The statement “increase in clinical benefit through VPH (UKB, physician)” indicates that the tool was seen as potentially valuable for clinical practice. This topic included four subthemes.

Improved awareness One participant highlighted that “individual elements are easy to recognize (UKF, physician),” suggesting that the visual representation supports clarity. Another remarked that “changes in a situation are perceived better with Visual Patient [Heart] than with conventional ECG (UKF, physician),” indicating a potential benefit in dynamic clinical environments. A further

comment highlighted the system’s salience: “advantage because various things are captured faster and more intuitively on the avatar” (UKF, physician).

Increased decision confidence Three participants reported that the system increased their confidence in clinical decision-making. One stated that they “felt very confident in most cases, quickly recognized and acted on (UKF, nurse),” suggesting the tool supported rapid and assured responses. Another reflected that “3–4 images of training are enough for a confident diagnosis, compared to ECG, which requires much more daily training, practice, and experience (UKF, nurse).” A further comment emphasized how the system may help resolve uncertainty: “Both are good: ECG and visualization. Each has its advantages. Confirms or refutes uncertainties (TUM, nurse)”

Time savings Six participants noted a speed advantage of VPH, such as: “instant overview, you get the diagnosis immediately (UKF, physician).” Another remarked, “much faster than ECG interpretation (UKB, nurse),” reinforcing the impression of time efficiency. Further, the participant explained, “it’s immediately clear where it is—atrium, ven-

Table 3 Major themes and subthemes, including counts, percentages, and illustrative examples. Question 2: Where Do You See Weaknesses or Areas for Improvement in the Technology?

Trust and Reliability (4/66 [6%] subtotal 18/66 [24%])	"Auto-ECG evaluations are often wrong" TUM, nurse
Accuracy and Reliability of Algorithms (3/66 [4%])	"Trust necessary that software recognizes, interprets, and visualizes the correct rhythm. Analysis must be correct" UKB, physician
Fear of Declining ECG Skills (2/66 [3%])	"Training could suffer if ECG interpretation is not practiced hands-on" UKB, physician
Desire for Integration with Conventional ECG (6/66 [9%])	"It should make sense to display the primary data source as well, not just the avatar alone" UKB, physician
Lack of Perceived Value (1/66 [2%])	"No significant benefit of visualization with years of ECG experience: "For me, it's the same" UKB, nurse
Improvement Suggestions (7/66 [11%] subtotal 9/66 [14%])	"Shorter list of pathologies" UKB, nurse"Heart less relevant than arrow" UKF, nurse"Patient has little personality" UKF, nurse
Desire for Manufacturer-Neutral Language (2/66 [3%])	"Philips 'diagnoses' not intuitive (e.g., missed beat)" UKB, physician"Missed beat, VES couplet. What is that" TUM, nurse
Feedback On Specific Visualizations (6/66 [9%] subtotal 31/66 [46%])	"Not all animations are quickly recognizable" TUM, physician"Tachycardia changes become difficult" UKF, physician
ST-Segment (6/66 [9%])	"ST deviations need to be more clearly differentiated" UKF, nurse"ST visualization localizations not entirely clear" UKF, physician"In 2D visualization anterior is on the right, posterior on the left — you have to remember it" UKF, physician
Atrial Visualizations (2/66 [3%])	"P wave/curve not understood" TUM, nurse"Make sinus node red (more noticeable)" TUM, physician
Ventricular Visualizations (11/66 [17%])	"Bigeminy/Trigeminy harder to distinguish due to frequency" TUM, nurse"Two arrows for Trigeminy, for example" UKF, physician"Ventricular differences are not entirely clear, could still need some help" UKF, nurse
Pacemaker (2/66 [3%])	"Pacemaker visualizations: unclear what is 'working'" UKB, nurse"Pacemaker cable could go into the arrow. Functional/non-functional pacemaker visually different, e.g., with scissors" UKB, nurse
Asystole (3/66 [5%])	"Asystole and unknown status confused, maybe omit arrow for unknown" UKF, physician"Yellow dot for asystole is misleading, looks like a block" UKF, nurse
More Training Required (5/66 [8%])	"Requires training" TUM, physician"Teaching is important" UKF, physician
Study-Specific Feedback (3/66 [5%])	"It was very short. Does not allow systematic evaluation" UKB, physician"Time issue in the study, uncertainty due to short duration" TUM, nurse"Would be easier if it could be seen for longer (in the study)" UKF, nurse

tricle, etc. (UKB, nurse)", suggesting that anatomical clarity contributes to faster recognition.

Reduced workload Three participants experienced the avatar-based visualization as less mentally demanding. One stated, "*found the representation on the avatar more relaxing than interpreting the ECG in a short time (UKB, physician)*", indicating reduced stress under time pressure. Another described it simply as "*easier*," suggesting lower cognitive load. A third participant noted, "*facilitates visual diagnosis compared to a single-lead ECG (TUM, nurse)*", pointing to improved rhythm interpretation efficiency.

User-friendliness

Five participants commented, one noted it was "*intuitive, easy to learn (TUM, physician)*", while another emphasized that it was "*very user-friendly*." The design's simplicity was also appreciated, as reflected in the comment "*easy to remember (UKF, physician)*," highlighting its positive effect on memory and recall. This topic included four sub-themes.

Quick and easy learnability Four participants noted that the system was easy and quick to learn and understand. One stated it was "*great for visual learners (TUM,*

nurse)", while another remarked, "*with more teaching, it has incredible potential compared to standard ECG analyses (UKF, nurse)*". The learning curve was described as: "*with good training, it is easier than something highly complex (TUM, nurse)*".

Understandability across experience levels One noted that the system may be beneficial for users with limited ECG experience. "*Diagnoses are immediately obvious, even for those inexperienced with ECGs (UKF, physician)*", while another emphasized that it is "*good for new employees and those with limited ECG knowledge (UKB, nurse)*". A third participant found it "*particularly valuable for nursing staff (UKF, nurse)*", highlighting its potential in interprofessional settings.

Design efficiency Eight participants appreciated the simplicity and clarity of the visual representation. One noted that it is "*clear and well-organized (TUM, nurse)*", while another pointed out the benefit of a "*compact, concise, quick overview (UKF, physician)*." A third remarked, "*the simplicity—there are only three parts to focus on (UKB, physician)*", indicating that the streamlined design supports rapid comprehension.

Aesthetic appeal One described VPH as a “*beautiful presentation, intuitive (TUM, nurse)*”, while another noted that it “*looks better*”.

Feedback on specific visualizations

This topic included four subthemes that addressed various aspects of visual representation.

ST-segment One participant noted that “*ST-segments are also easy to identify (TUM, physician)*”, while another highlighted that “*ST deviations are easier to grasp for the inexperienced (UKF, physician)*”. A third participant emphasized its clinical relevance: “*ST helps especially because it is not easy to identify (TUM, physician)*”.

Atrial visualizations “*Atrial activity is better recognizable, quickly at a glance (UKF, physician)*,” while also highlighting “*P-wave is good*”.

Ventricular visualizations One participant noted a superiority for VPH in “*bigeminy and trigeminy patterns (UKF, physician)*”.

Pacemaker Three participants highlighted the perceived value of pacemaker-related visualizations. “*Pacemaker detection is good (UKF, nurse)*,” and another stated, “*Pacemaker is easy to interpret (TUM, physician)*”. Additional comments described the representation as “*simple*” and praised the inclusion of “*extras like pacemaker leads (UKF, nurse)*”.

Potential use-cases

One participant noted it would be “*intuitive in emergency situations (TUM, nurse)*”, while another emphasized its visibility, stating it is “*clearly visible from a distance (TUM, nurse)*”.

Non-specific positive feedback

Some participants expressed general appreciation for the concept. One described the system as “*nicely done*”, while another noted an “*emotional connection*,” adding, “*you want the avatar on the screen to be okay (UKB, physician)*”.

Question 2: where do you see weaknesses or areas for improvement in the technology?

Trust and reliability

Two participants expressed concerns about placing too much trust in computer-analyzed visual representations. One participant questioned whether clinical responsibility might be delegated too quickly: “*Because it is already evaluated, by what? AI, Philips algorithm? (UKF, physician)*” Another participant remarked: “*reliance on the avatar means reliance on the patient (TUM, nurse)*”,

highlighting the subtle risk that users might assume the avatar perfectly reflects the patient’s real condition, without critically examining the underlying data.

Accuracy and reliability of algorithms Two participants raised concerns about whether the system reliably interprets ECG data. One questioned: “*does it actually match the ECG? (UKF, physician)*” indicating uncertainty about the fidelity of the underlying *Philips ST/AR* algorithm and the entire system. Another emphasized that “*trust [is] necessary that the software recognizes, interprets, and visualizes the correct rhythm (UKB, physician)*”, underlining the importance of algorithmic accuracy. A third comment reflected scepticism in the underlying algorithm: “*lack of trust. Does it recognize pathologies correctly? (UKB, physician)*”.

Fear of declining ECG skills Two participants expressed concern that using VPH could erode traditional ECG competence over time. “*Training could suffer if ECG interpretation is not practiced hands-on (UKF, physician)*”, while also expressing a “*fear of losing information*” when relying too much on simplified visualizations.

Desire for integration with conventional ECG Four participants wished to combine VPH with conventional ECG output, stating, “*VPH not alone, but ECG and VPA combined (UKB, physician)*”. Another remarked, “*higher accuracy with ECG: can see more on the ECG, in which lead the problem lies (UKB, physician)*”, indicating that ECG may provide more detail. A third participant noted that “*it should make sense to display the primary data source as well, not just the avatar alone (UKF, nurse)*”, highlighting a desire for transparency and parallel information.

Lack of perceived value One participant with many years of ECG experience stated that the visualization did not provide additional benefit, saying, “*For me, it’s the same (UKF, physician)*”.

Improvement suggestions

Five participants offered various suggestions to further enhance the VPH system. One proposed a more focused display: “*[It] would be easier if fewer visualizations/diagnoses were reduced to the essentials. (UKF, nurse)*” Another participant suggested including technical feedback: “*signal quality index missing (UKF, physician)*”. A third suggestion was to introduce additional visual clarity “*by zooming in (UKB, physician)*”.

Desire for manufacturer-neutral language Four participants wished for clearer terminology in the underlying *Philips ST/AR algorithm*. One stated: “*Philips ‘diagnoses’*

not intuitive (e.g., missed beat) (TUM, nurse)", expressing confusion over proprietary wording. Another asked: "missed beat, VES couplet — what is that (TUM, nurse)?" indicating a desire for more standardized language.

Feedback on specific visualizations

Participants provided a range of comments on the clarity and distinctiveness of individual visual elements. One stated that "some patterns are too similar to differentiate (ST inferior) (UKF, physician)". Additional feedback noted that "not all animations are quickly recognizable" and that "tachycardia changes become difficult (UKB, physician)", suggesting limits to visual immediacy. This was also reflected in a specific case: "missed beat: possibly missed the arrow once, but only briefly", highlighting reduced recognizability. Within this topic, we identified and included four sub-themes.

ST-segment Four participants expressed difficulty in interpreting ST-segment visualizations. "ST inferior vs. widespread [multiple] is difficult to differentiate (UKF, nurse)", while another stated bluntly: "ST is confusing". One comment addressed spatial confusion: "In 2D visualization anterior is on the right, posterior on the left — you have to remember it, (UKB, nurse)" highlighting the need for more intuitive spatial mapping.

Atrial visualizations Two participants reported difficulties in interpreting atrial features. "P wave/curve [was] not understood (TUM, nurse)", suggesting a need for clearer design or improved training. Another recommended enhancement of visual salience: "make sinus node red (more noticeable)".

Ventricular visualizations One participant noted that "bigeminy/trigeminy [is] harder to distinguish due to frequency (UKF, physician)". At the same time, another provided feedback on general clarity, such as "ventricular differences are not entirely clear, could still need some help (UKF, physician)".

Pacemaker Three participants found the pacemaker visualizations unclear. One commented that it was "unclear what is 'working' and what is 'defective' (UKB, nurse)", indicating ambiguity in function status. Another suggested improving the design, for example: "pacemaker cable could go into the arrow. [Make] functional/non-functional pacemaker visually different, e.g., with scissors (UKB, physician)".

Asystole Two participants expressed confusion about how asystole and unknown rhythm states are visualized. One noted that "asystole and unknown status [are] confused, maybe omit arrow for unknown (UKF, nurse)".

Another remarked that the "yellow dot for asystole is misleading, looks like a block (UKF, physician)". A third participant felt that "asystole [is] visually not severe enough (TUM, physician)".

More training required

Six participants emphasized the need for more instruction than in the study setup. "Training should be more comprehensive (UKF, nurse)", while commenting, "requires 1–2 rounds of training". A further participant reflected that "towards the end, it was difficult with only the training video (TUM, nurse)", indicating a desire for more structured learning support.

Study-specific feedback

Three participants felt that the study's conditions limited their ability to perform at their best. "It was very short. Does not allow systematic evaluation (UKB, physician)", while stating, "time issue in the study, uncertainty due to short duration". A third statement suggested that "it would be easier if it could be seen for longer (TUM, nurse)".

Discussion

In this study, we examined qualitative feedback from 41 anaesthesia clinicians, nurses, and physicians across three university hospitals in Germany. Following their participation in a simulation study in which they were asked to interpret arrhythmias and ECGs using both the new VPH system and conventional 12-lead ECGs, participants were surveyed and answered two open-ended questions: one regarding perceived benefits, and one concerning potential disadvantages or suggestions for improvement.

Visualization innovations

The *Philips Visual Patient Avatar* integrates multiple vital signs into a single intuitive visualization, using dynamic colors, shapes, animations, and icons [11]. It improves the perception of vital signs, yielding higher detection rates and greater diagnostic confidence than conventional monitors [25, 26]. Other innovative monitoring displays have been explored since the 2000s. AlertWatch (AlertWatch, Inc., Ann Arbor, MI, US) integrates patient comorbidities, lab values, and live physiological data into animated, color-coded organ icons, improving intraoperative process measures [27–29]. Respiratory-focused systems, such as the Dynamic Lung panel (Hamilton Medical AG, Bonaduz, Switzerland) and PulmoSight (Mindray Medical International Limited, Shenzhen, China), use animated anatomical lungs to visualize tidal volume, compliance, resistance, and patient-triggered breaths in real time, facilitating faster recognition and management of ventilatory events [30–34]. Advanced

hemodynamic displays, including HemoSight (Mindray) and the Physiology screen (BD Franklin Lakes, NJ, USA), represent the heart, lungs, blood, and vessels with dynamic animations of cardiac output, vessel constriction, oxygenation, and lung fluid status [35–37]. The Alarm Status Visualizer and UniView (Masimo Corp., Irvine, CA, US) display alarm conditions on a 3D body image, highlighting abnormal organs with color and motion [38]. These approaches share a common goal: integrating complex, multi-parameter data into intuitive visualizations that enhance situation awareness, reduce cognitive load, and support rapid clinical decision-making. The current text-based output of the Philips ST/AR algorithm presents several limitations. Diagnostic messages are displayed only after an event has been detected, limiting anticipatory awareness. In addition, the output lacks baseline or trend information, making it difficult to contextualize findings. Finally, the use of manufacturer-specific terminology may introduce ambiguity and reduce interpretability for clinical users. The VPH does not replace or modify the underlying diagnostic algorithm; rather, it provides a visual representation of algorithm-derived information. Importantly, the VPH itself does not generate additional alarms; it serves solely as a visual indication. In a recent simulation study, *Philips Visual Patient Avatar* improved the correct identification of emergency diagnoses, even when participants initially assigned lower perceived usability to the new system than to familiar standard monitors [39].

Qualitative feedback from study participants

Overall, participants responded positively to the technology. This was reflected not only in the number and content of specific and non-specific positive statements, but also in the fact that substantially more responses were given to the question about advantages than to the question about disadvantages, despite participants encountering the technology for the first time during the study and having extensive prior experience with conventional ECG interpretation. Thematic template analysis of the surveys revealed several recurring perceived benefits. Participants often mentioned improved recognition of pathologies, facilitated by the rapid interpretability of a single visual representation compared to the multiple curves of a traditional ECG. Visualizations were frequently described as intuitive, which was associated with greater decision confidence and reduced cognitive workload. These observations are consistent with previous research linking visual technologies to increased confidence and lower task load in clinical decision-making [11–14]. Furthermore, the system was perceived as user-friendly, aesthetically appealing, and easy to learn. Participants emphasized its potential to support understanding across different user groups, including less experienced nurses,

physicians, and staff from other specialties. Participants also highlighted the system's potential in real-world clinical settings, particularly under high workload or when improved recognition is needed, for example, when observing the display from a distance. The system's low complexity, combined with the high salience of relevant information, aligns well with core components of situation awareness as described in Mica Endsley's model, which posits that low cognitive demand, clarity, and quick information transfer support situation awareness and decision-making [8, 19]. While responses to the first question centered on these benefits, the second question elicited valuable suggestions and critical reflections. Several participants expressed concerns about overreliance on pre-analyzed visualizations. One participant noted, "*reliance on the avatar means reliance on the patient*", implying that depending solely on the avatar without verifying the underlying data might create a false sense of security or lead to a loss of direct clinical connection. This skepticism mirrors broader challenges associated with the clinical adoption of automated or AI-based decision-support tools [40, 41]. Given that VPH is based on the *Philips ST/AR algorithm*, which automatically interprets ECG data, some participants expressed skepticism regarding the algorithm's reliability and emphasized the need to critically evaluate what the visualization represents and how it is generated. To mitigate these concerns, participants recommended integrating the avatar with conventional ECG output to combine the intuitive, fast overview offered by VPH with the gold-standard diagnostic value of the traditional 12-lead ECG waveforms [15]. This notion aligns with findings from studies comparing visual monitoring systems, in which clinicians benefited from an integrated display that enabled early visual recognition, followed by quantitative validation [42]. Concerns were raised about potential skill degradation, specifically, regular ECG interpretation skills might be lost over time if the avatar is used in isolation. Participants also stressed the importance of adequate training. Several remarked that the short instructional video used in the study was insufficient and called for more comprehensive training to ensure confident application. There were also suggestions to improve the system's terminology, with a preference for more intuitive, manufacturer-neutral language. Although it is not clear whether the terms criticized ("*missed beat*", "*VES couplet*") are truly manufacturer-specific, the feedback indicates a need for more transparent, universally understandable diagnostic labels, particularly if paired with visual elements. Feedback on specific visualizations was rich and multifaceted. Participants welcomed the inclusion of dedicated visualizations for ST-segments, ventricular rhythms, and pacemaker rhythms, noting that these are often overlooked or difficult to interpret in the conventional format. However,

they also offered concrete suggestions for improvement, such as enhancing differentiation among ST-segment localizations, clarifying pacemaker status, and simplifying the visual distinction between rhythm types, such as bigeminy, trigeminy, and couplets. Participants identified monitoring under high workload and from a distance as potential areas where the technology could be particularly beneficial – both contexts in which the underlying Visual Patient Avatar has already demonstrated advantages in quantitative studies [43, 44]. One feature that stood out as particularly valuable was the zoom function, which enlarges the avatar's heart for easier viewing. In terms of study-specific feedback, some participants noted that the visualizations were only displayed for a brief duration (6 s), which limited their ability to evaluate them systematically. Although this was intentionally designed to measure first-glance effectiveness, it may have constrained more nuanced assessments. At-a-glance monitoring is common in patient monitoring, the context for which this technology is intended [45, 46].

Need for integration of standard and innovative visualizations

Our findings support the complementary use of conventional ECG displays and the VPH visualization. While the Philips “ST/AR algorithm” can detect arrhythmias using a limited set of leads, human interpretation of 12-lead ECGs remains the clinical gold standard, particularly for assessing ST-segment deviations. However, future developments in AI-based ECG analysis may further expand automated diagnostic capabilities [47]. The VPH was designed to alert anaesthesia professionals with varying levels of expertise to cardiac pathologies. In contrast to traditional text-based alarms, which may be overlooked, the VPH provides an immediate visual overview that highlights relevant abnormalities, translating algorithm-detected diagnoses with the location of the pathology explicitly mapped onto the heart: ventricular fibrillation is shown with arrows in the apex of the heart, atrial arrhythmias at the top right corner (right atrium), and bigeminy is visualized along the normal conduction pathway (from right top corner to apex) with an upstroke arrow indicating ventricular extrasystole (see the Supplementary Video 1 for full visualizations). Combining conventional ECG displays with the VPH avatar could reduce cognitive load during task switching, enhance situational awareness, and support safer decision-making [48].

Limitations

This study has several limitations. Capturing statements through field notes may introduce selective capture, loss of context, and potential facilitator bias. To mitigate this, all recorded responses were read back verbally to the participants immediately after documentation, allowing

them to confirm, clarify, or correct the recorded statements. In addition, the template analysis was conducted separately and retrospectively after the initial documentation process. Translation of participant statements from German to English using ChatGPT (4o) may introduce bias and normalize phrasing. We tried to mitigate this by using human verification and comparing translations with the original statements; however, some bias may still persist. The brief six-second scenario presentation may favor the VPH visualization, as it is specifically designed for rapid comprehension. While this duration is insufficient for detailed ECG analysis, it aligns with the study's focus on intuitive, “at-a-glance” information. The Philips “ST/AR algorithm” has not yet been extensively validated in large-scale randomized trials, and its clinical value therefore remains to be fully established. Nonetheless, since the algorithm is certified and already in use across a wide range of Philips monitoring systems, developing a dedicated visualization like VPH may enhance usability and user engagement, ultimately helping unlock the algorithm's true clinical value in practice. Participants in our study were not recruited through random sampling but rather based on the availability of physicians and nurses who participated in the initial simulation sessions. This approach may have introduced selection bias, potentially favoring a younger, more technology-friendly sample, thereby influencing the perceptions and experiences reported in the qualitative interviews. There is, however, little reason to believe that staff availability would introduce significant bias into users' perceptions of VPH. To enhance the transferability of our findings, we conducted this research as a multi-center and multi-professional study involving three major university hospitals, incorporating diverse perspectives from different clinical settings and professional roles. The feedback reflects initial impressions, as this was the first VPH prototype evaluation. Future studies should explore how these perceptions evolve with real-life exposure in clinical practice.

Conclusion

In summary, VPH was well received by participants who recognized its potential to enhance situation awareness after their first exposure to the technology. Their survey responses revealed numerous qualities: simplicity, clarity, low cognitive load, and strong visual cues, which align with human-centered design principles. At the same time, participants offered thoughtful and constructive suggestions that highlight important considerations regarding explainability, trust, and the combined use of conventional ECG waveforms and VPH. Future studies could focus on more complex, scenario-based simulations, such as multi-patient monitoring situations, and

eventually involve real patients in clinical environments, fully integrated into the broader Visual Patient platform.

Abbreviations

AF	Atrial fibrillation
AR	Arrhythmia
BASEC	Business Administration System for Ethics Committees (Switzerland)
ECG	Electrocardiogram
ICU	Intensive care unit
IQR	Interquartile range
NASA-TLX	National Aeronautics and Space Administration Task Load Index
NSVT	Non-sustained ventricular tachycardia
OR	Operating room
PACU	Post-anaesthesia care unit
QRS	QRS complex
R–R interval	Interval between successive R waves
SD	Standard deviation
ST	ST segment
ST/AR	ST and Arrhythmia
SVT	Supraventricular tachycardia
TUM	TUM University Hospital Munich
UKB	University Hospital Bonn
UKF	University Hospital Frankfurt am Main
USZ	University Hospital Zurich
VPH	Visual Patient Heart
VES	Ventricular ectopic beat

Supplementary Information

The online version contains supplementary material available at <https://doi.org/10.1186/s12911-026-03578-y>.

Supplementary Material 1
Supplementary Material 2
Supplementary Material 3

Acknowledgements

The authors thank all study participants for their time, engagement, and valuable feedback.

Author contributions

ME: Conceptualization, Data Collection, Data Curation, Investigation, Visualization, Writing – Original Draft. CAH: Conceptualization, Technology Development (Visual Patient Heart), Data Collection, Data Curation, Investigation, Visualization, Writing – Original Draft. TRR: Data Collection. AR: Data Collection, Investigation. AD: Data Collection. FP: Data Collection. FJR: Data Collection. SB: Investigation, Writing – Original Draft. SL: Project Coordination (TUM), Data Collection. GM: Project Coordination (UKB), Data Collection. KZ: Resources, Project Coordination (UKF), Data Collection. DWT: Conceptualization, Project Administration, Supervision, Resources, Technology Development (Visual Patient Heart), Project Coordination (USZ), Data Collection. All authors contributed to Writing, reviewing, & Editing and approved the final manuscript.

Funding

This research received no specific grant from funding agencies in the public, commercial, or not-for-profit sectors. Travel expenses were covered from an unrestricted research account funded through royalty payments from Philips Visual Patient licensing agreements.

Data availability

The datasets generated and/or analyzed during the current study are included in the supplementary materials of this article.

Declarations

Ethics approval and consent to participate

This study was conducted in accordance with the Declaration of Helsinki. Written informed consent was obtained from all participants, and all data were anonymized before analysis. The study received a declaration of non-jurisdiction from the Cantonal Ethics Commission of the Canton of Zurich, Switzerland (BASEC-Nr.: Req-2024-00353), as it did not fall within the scope of the Swiss Human Research Act. Ethical approval was obtained from all participating centers in Germany: Munich (2024-383-S-CB), Bonn (AZ 2024-209-BO), and Frankfurt (#2024 – 1760).

Consent for publication

Not applicable.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the authors used ChatGPT-4 (OpenAI, San Francisco, CA, USA) to support language editing and translation. The authors reviewed and edited all content and take full responsibility for the integrity and accuracy of the final manuscript.

Competing interests

ME and CAH are inventors of the Visual Patient Heart technology. TRR is an inventor of Visual Patient Predictive and Visual Blood, with intellectual property held by the University of Zurich and Philips, and receives research funding, honoraria, and travel support through joint development and licensing agreements from Philips. KZ has received honoraria for participation in advisory board meetings for Haemonetics and Vifor and received speaker fees from CSL Behring, Masimo, Pharmacosmos, Boston Scientific, Salus, iSEP, Edwards, and GE Healthcare. He is Principal Investigator of the EU Horizon 2020 project ENVISION and Horizon Europe project COVend and is a partner in the Horizon Europe project EDIHTA. He serves as CEO of the Christoph Lohfert Foundation and the Health, Patient Safety & PBM Foundation. DWT is an inventor of Visual Patient, Visual Patient Predictive, Visual Blood, Visual Clot, Visual Hemofilter, and Visual Patient Heart, with intellectual property held by Philips and the University of Zurich. DWT receives research funding, honoraria, royalties, and travel support through joint development and licensing agreements. Additional honoraria and travel support were provided by Instrumentation Laboratory–Werfen, the Swiss Foundation for Anaesthesia Research, and the International Symposium on Intensive Care and Emergency Medicine. DWT serves on the Philips Patient Safety Advisory Board. All other authors declare no competing interests. Philips provided no funding for the development of Visual Patient Heart and had no role in the design, conduct, analysis, or reporting of this study.

Author details

¹Department of Anesthesiology and Intensive Care, TUM School of Medicine and Health, Technical University of Munich, Ismaningerstrasse 22, 81675 Munich, Germany

²Institute of Anesthesiology and Perioperative Medicine, University of Zurich, University Hospital Zurich, Raemistrasse 100, Zurich 8091, Switzerland

³Department of Anesthesiology and Intensive Care Medicine, University Hospital Bonn, Venusberg-Campus 1, 53127 Bonn, Germany

⁴Department of Anaesthesiology, Intensive Care Medicine and Pain Therapy, Goethe University Frankfurt, University Hospital Frankfurt, Theodor-Stern-Kai 7, 60590 Frankfurt am Main, Germany

⁵Department of Cardiology, University of Zurich and University Hospital Zurich, Raemistrasse 100, Zurich 8091, Switzerland

Received: 21 January 2026 / Accepted: 18 May 2026

Published online: 26 May 2026

References

- Klein AA, Meek T, Allcock E, Cook TM, Mincher N, Morris C, et al. Recommendations for standards of monitoring during anaesthesia and recovery 2021: Guideline from the Association of Anaesthetists. *Anaesthesia*. 2021;76(9):1212–23.

2. Gelb AW, Morris WW, Johnson W, Merry AF, Abayadeera A, Belli N, et al. World Health Organization-World Federation of Societies of Anaesthesiologists (WHO-WFSA) International Standards for a Safe Practice of Anesthesia. *Anesth Analg*. 2018;126(6):2047–55.
3. Evans L, Rhodes A, Alhazzani W, Antonelli M, Coopersmith CM, French C, et al. Surviving sepsis campaign: international guidelines for management of sepsis and septic shock 2021. *Intensive Care Med*. 2021;47(11):1181–247.
4. Drews FA, Westenskow DR. The right picture is worth a thousand numbers: data displays in anesthesia. *Hum Factors*. 2006;48(1):59–71.
5. Asgari E, Kaur J, Nuredini G, Balloch J, Taylor AM, Sebire N, et al. Impact of Electronic Health Record Use on Cognitive Load and Burnout Among Clinicians: Narrative Review. *JMIR Med Inf*. 2024;12:e55499.
6. Schulz CM, Burden A, Posner KL, Mincer SL, Steadman R, Wagner KJ, et al. Frequency and Type of Situational Awareness Errors Contributing to Death and Brain Damage: A Closed Claims Analysis. *Anesthesiology*. 2017;127(2):326–37.
7. Schulz CM, Krautheim V, Hackemann A, Kreuzer M, Kochs EF, Wagner KJ. Situation awareness errors in anesthesia and critical care in 200 cases of a critical incident reporting system. *BMC Anesthesiol*. 2016;16:4.
8. Schulz CM, Endsley MR, Kochs EF, Gelb AW, Wagner KJ. Situation awareness in anesthesia: concept and research. *Anesthesiology*. 2013;118(3):729–42.
9. Hesse PN, Schmitt C, Klingenhoefer S, Bremmer F. Preattentive Processing of Numerical Visual Information. *Front Hum Neurosci*. 2017;11:70.
10. Drews FA. Advances in Patient Safety Patient Monitors in Critical Care: Lessons for Improvement. In: Henriksen K, Battles JB, Keyes MA, Grady ML, editors. *Advances in Patient Safety: New Directions and Alternative Approaches. Performance and Tools. Volume 3*. Rockville (MD): Agency for Healthcare Research and Quality (US); 2008.
11. Gasciauskaitė G, Lunkiewicz J, Roche TR, Spahn DR, Nothiger CB, Tscholl DW. Human-centered visualization technologies for patient monitoring are the future: a narrative review. *Crit Care*. 2023;27(1):254.
12. Hunn CA, Lunkiewicz J, Nothiger CB, Tscholl DW, Gasciauskaitė G. Qualitative exploration of anesthesia providers' perceptions regarding Philips Visual Patient Avatar in clinical practice. *Bioeng (Basel)*. 2024;11(4).
13. Radavičiute I, Hunn CA, Lunkiewicz J, Milovanovic P, Willms JF, Nothiger CB, et al. Survey-based qualitative exploration of user perspectives on the Philips visual patient avatar in clinical situation management. *Sci Rep*. 2024;14(1):22176.
14. Lunkiewicz J, Fries D, Milovanovic P, Nothiger CB, Tscholl DW, Gasciauskaitė G. Pediatric anesthesia providers' perspective on the real-life implementation of the Philips Visual Patient Avatar: a qualitative study. *Children (Basel)*. 2023;10(12).
15. Thompson A, Balser JR. Perioperative cardiac arrhythmias. *Br J Anaesth*. 2004;93(1):86–94.
16. Kwon CH, Kim SH. Intraoperative management of critical arrhythmia. *Korean J Anesthesiol*. 2017;70(2):120–6.
17. Zong W, Kresge S, Lu H, Wang J, editors. A real-time ST-segment monitoring algorithm based on a multi-channel waveform-length-transform method for Q-onset and J-point detection. In: *Computing in Cardiology 2014*; 2014 Sep 7–10; 2014.
18. Koninklijke Philips NV. PM - Arrhythmia monitoring ST AR algorithm application note. Philips; 2020.
19. Endsley MR, Jones DG. Designing for situation awareness: an approach to user-centered design. 3rd ed. Boca Raton (FL): CRC Press; 2025.
20. Oury JD, Ritter FE. How User-Centered Design Supports Situation Awareness for Complex Interfaces. In: Oury JD, Ritter FE, editors. *Building Better Interfaces for Remote Autonomous Systems: An Introduction for Systems Engineers*. Cham: Springer International Publishing; 2021. pp. 21–35.
21. Hunn CA, Ebensperger M, Roche TR, Rahrish A, Delis A, Piekarski F, et al. Using Visual Patient Heart to improve anaesthesia professionals' ECG interpretation and arrhythmia situation awareness: a quantitative study. *Res Square*. 2026.
22. Symon G, Cassell C. Qualitative organizational research: core methods and current challenges. London (UK): SAGE Publications; 2012. Available from: <https://sk.sagepub.com/dict/mono/qualitative-organizational-research-core-methods-and-current-challenges/toc>.
23. Gasciauskaitė G, Lunkiewicz J, Schweiger G, Budowski AD, Henckert D, Roche TR, et al. User Perceptions of Visual Blood: An International Mixed Methods Study on Novel Blood Gas Analysis Visualization. *Diagnostics (Basel)*. 2023;13:19.
24. Gasciauskaitė G, Castellucci C, Malorgio A, Budowski AD, Schweiger G, Kolbe M, et al. User Perceptions of Visual Clot in a High-Fidelity Simulation Study: Mixed Qualitative-Quantitative Study. *JMIR Hum Factors*. 2024;11:e47991.
25. Bergauer L, Braun J, Roche TR, Meybohm P, Hottenrott S, Zacharowski K, et al. Avatar-based patient monitoring improves information transfer, diagnostic confidence and reduces perceived workload in intensive care units: computer-based, multicentre comparison study. *Sci Rep*. 2023;13(1):5908.
26. Viautour J, Naegeli L, Braun J, Bergauer L, Roche TR, Tscholl DW, et al. The Visual Patient Avatar ICU Facilitates Information Transfer of Written Information by Visualization: A Multicenter Comparative Eye-Tracking Study. *Diagnostics (Basel)*. 2023;13:22.
27. Kheterpal S, Shanks A, Tremper KK. Impact of a Novel Multiparameter Decision Support System on Intraoperative Processes of Care and Postoperative Outcomes. *Anesthesiology*. 2018;128(2):272–82.
28. Colquhoun DA, Davis RP, Tremper TT, Mace JJ, Gombert JM, Sheldon WD, et al. Design of a novel multifunction decision support/alerting system for in-patient acute care, ICU and floor (AlertWatch AC). *BMC Anesthesiol*. 2021;21(1):196.
29. Tremper KK, Mace JJ, Gombert JM, Tremper TT, Adams JF, Bagian JP. Design of a Novel Multifunction Decision Support Display for Anesthesia Care: AlertWatch® OR. *BMC Anesthesiol*. 2018;18(1):16.
30. Wachter SB, March JA, Syroid ND, Drews FA, Westenskow DR. A New Metaphor to Display Critical Pulmonary Events during Anesthesia. *J Am Med Inf Assoc*. 2002;9(6 Suppl 1):s108–9.
31. Wachter SB, Agutter J, Syroid N, Drews F, Weinger MB, Westenskow D. The employment of an iterative design process to develop a pulmonary graphical display. *J Am Med Inf Assoc*. 2003;10(4):363–72.
32. Wachter SB, Johnson K, Albert R, Syroid N, Drews F, Westenskow D. The evaluation of a pulmonary display to detect adverse respiratory events using high resolution human simulator. *J Am Med Inf Assoc*. 2006;13(6):635–42.
33. Hamilton Medical AG. Das Ventilation Cockpit – klare Darstellung komplexer Daten: Hamilton Medical AG; 2025 [Available from: https://www.xn--hamilton-medical-7s9h.com/de_CH/Products/Technologies/Ventilation-Cockpit.html]
34. Mindray SV, Ventilator SV. Mindray; 2026 [Available from: <https://www.mindray.com/en/products/ventilators/sv800-sv600>]
35. Company BD. Advanced Hemodynamic Monitoring Solutions: BD; 2026 [Available from: <https://www.bd.com/en-us/products-and-solutions/solution/s/advanced-hemodynamic-monitoring-solutions>]
36. Mindray, HemoSight Clinical Information Leaflet. : Mindray; 2015 [Available from: <https://www.mindray.com/en/community/pmls-global-clinical-institut-e/featured-content/hemosight-clinical-information-leaflet>]
37. Michard F, Wong A, Kanoore Edul V. Visualizing hemodynamics: innovative graphical displays and imaging techniques in anesthesia and critical care. *Crit Care*. 2025;29(1):3.
38. Masimo. UniView Smart Display: Masimo; 2026 [Available from: <https://www.masimo.de/products/smart-displays/uniview/>]
39. Roche TR, Said S, Braun J, Maas EJC, Machado C, Grande B, et al. Avatar-based patient monitoring in critical anaesthesia events: a randomised high-fidelity simulation study. *Br J Anaesth*. 2021;126(5):1046–54.
40. Henckert D, Malorgio A, Schweiger G, Raimann FJ, Piekarski F, Zacharowski K, et al. Attitudes of anesthesiologists toward artificial intelligence in anesthesia: a multicenter, mixed qualitative-quantitative study. *J Clin Med*. 2023;12(6).
41. Pinsky MR, Bedoya A, Bihorac A, Celi L, Churpek M, Economou-Zavlanos NJ, et al. Use of artificial intelligence in critical care: opportunities and obstacles. *Crit Care*. 2024;28(1):113.
42. Akbas S, Said S, Roche TR, Nothiger CB, Spahn DR, Tscholl DW, et al. User Perceptions of Different Vital Signs Monitor Modalities During High-Fidelity Simulation: Semiquantitative Analysis. *JMIR Hum Factors*. 2022;9(1):e34677.
43. Pfarr J, Ganter MT, Spahn DR, Nothiger CB, Tscholl DW. Effects of a standardized distraction on caregivers' perceptive performance with avatar-based and conventional patient monitoring: a multicenter comparative study. *J Clin Monit Comput*. 2020;34(6):1369–78.
44. Milovanovic P, Braun J, Hunn CA, Lunkiewicz J, Tscholl DW, Gasciauskaitė G. Avatar-based versus conventional patient monitoring with distant vision: a computer-based simulation study. *J Clin Monit Comput*. 2025;39(5):1065–1075.
45. Ford S, Birmingham E, King A, Lim J, Ansermino JM. At-a-glance monitoring: covert observations of anesthesiologists in the operating room. *Anesth Analg*. 2010;111(3):653–8.
46. Hofmaenner DA, Herling A, Klinzing S, Wegner S, Lohmeyer Q, Schuepbach RA, et al. Use of eye tracking in analyzing distribution of visual attention among critical care nurses in daily professional life: an observational study. *J Clin Monit Comput*. 2021;35(6):1511–8.
47. Herman R, Mumma BE, Hoyne JD, Cooper BL, Johnson NP, Kisova T, et al. AI-Enabled ECG Analysis Improves Diagnostic Accuracy and Reduces False

STEMI Activations: A Multicenter U.S. Registry. *JACC Cardiovasc Interv.* 2026;19(2):145–56.

48. Trafton JG, Altmann EM, Brock DP, Mintz FE. Preparing to resume an interrupted task: effects of prospective goal encoding and retrospective rehearsal. *Int J Hum-Comput Stud.* 2003;58(5):583–603.

Publisher's note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.