Avatar-based versus conventional vital signs display in a central monitor for monitoring multiple patients: A multicenter computer-based laboratory study

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Abstract

Background Maintaining adequate situation awareness is crucial for patient safety. Previous studies found that the use of avatar-based monitoring (Visual Patient Technology) improved the perception of vital signs compared to conventional monitoring showing numerical and waveform data; and was further associated with a reduction of perceived workload. In this study, we aimed to evaluate the effectiveness of Visual Patient Technology on perceptive performance and perceived workload when monitoring multiple patients at the same time, such as in central station monitors in intensive care units or operating rooms.Methods A prospective, within-subject, computer-based laboratory study was performed in two tertiary care hospitals in Switzerland in 2018. Thirty-eight physician and nurse anesthetists volunteered for the study. The participants were shown four different central monitor scenarios in sequence, where each scenario displayed two critical and four healthy patients simultaneously for 10 or 30 seconds. After each scenario, participants had to recall the vital signs of the critical patients. Perceived workload was assessed with the National Aeronautics and Space Association Task-Load-Index (NASA TLX) questionnaire.Results In the 10-second scenarios, the median number of perceived vital signs significantly improved from 7 to 11 using avatar-based versus conventional monitoring with a median of differences of 5 vital signs, $p < 0.001$. At the same time, the median NASA TLX scores were significantly lower for avatar-based monitoring (67 vs. 77) with a median of differences of 5 points, $p = 0.024$. In the 30-second scenarios, vital sign perception and workload did not differ significantly.Conclusions In central monitor multiple patient monitoring, we found a significant improvement of vital sign perception and reduction of perceived cognitive workload using Visual Patient Technology, compared to conventional monitoring. The technology enabled improved assessment of patient status and may, thereby, increase situation awareness and enhance patient safety.

Background

The World Health Organization, in its guidelines for safe surgery, considers the continuous presence of a professionally trained and vigilant anesthesia provider using standardized patient monitoring to be of central importance for safe perioperative care. The range and scope of applied monitoring may vary but should match minimal requirements and never substitute clinical observation and assessment[1]. Patient monitoring displays large amounts of information and may include various acoustic and visual signals, e.g., alarm sounds, waveforms, and numbers. Anesthesia providers must invest high mental effort to observe patients and their appendant surroundings continuously, and to integrate these sensory inputs into a mental model of the current situation and the expected immediate future. A technical definition of situation awareness provided by Endsley is: “the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and a projection of their status in the near future”[2-4]. Maintaining situation awareness is an important non-technical skill as it enables informed decision making: To make a well-founded decision, a decision maker must first correctly assess the situation at hand. In the operating room and the intensive care unit, maintaining situation awareness goes beyond just patient monitoring and is a continually evolving multi-directional process that takes place between care providers and their environment, which may include, e.g., the patient, other team members, external and self-induced distractions. Actions and events like these, may change the care providers' mental model and influence their further actions[5].

Errors in situation awareness can occur on all three levels: 1. perception; 2. comprehension; 3. projection, but with a predominant proportion in perception and comprehension. A subcategory of perception errors is failure to detect or perceive data, which is available in a system, e.g., overlooking a value on a patient monitor even though it is displayed.[3-6] Although monitors are a vital source of information, observational studies have found that anesthetists look at monitors in 1- to 2-second glances and overall only during about 5% of the observed time.[7,8] It has also been found, that increasing the amount of information shown on monitors, reduces the ability to detect unexpected changes even when a visual event or change is in plain view[9-11]. This phenomenon is called inattentional blindness and is a major cause of situation awareness failure[12-14].

To improve situation awareness, minimize inattentional blindness, and potentially enhance patient safety, presentation of monitoring information can be redesigned. One possibility is through transformation of the multitude of numbers and waveforms on current monitors into objects and pictures, which may be simpler to interpret. One research group developed an interface that represents stroke volume and heart rate as a rectangle with variable height and width, and another group created a display that depicts pulmonary function data anatomically[15-17]. A review article found that object or graphical displays may result in a faster detection of changes and more successful treatment[18].

In a previous study, Visual Patient Technology, a situation awareness-based monitoring technology that displays patient status using a virtual animated patient avatar, improved the perception of vital sign information in anesthesia providers, reduced the perceived workload and received positive user feedback[19-21].

In this study, we aimed to evaluate whether or not the previously found effects of Visual Patient Technology can be replicated in monitoring multiple patients at the same time, as commonly used in current operating room and intensive care central station monitors.

The hypothesis of this study was that there would be an improvement in perceptive performance as well as in perceived workload with Visual Patient Technology, analogous to the previous study.

Methods

Study participants

We conducted this multicenter study in Switzerland with anesthesia providers from the University Hospital Zurich (USZ) and the Cantonal Hospital Winterthur (KSW). We included participants according to a predefined scheme so that in both centers the sample was gender-balanced and included the same number of participants of the three occupational groups of senior anesthetists, resident anesthetists, and subspecialized nurse anesthetists. This procedure enabled us to include a sample representative for all persons in the anesthesiology departments and reduced the risk of selection bias.

Study design

Study procedure

We conducted a computer-based laboratory study. The participants sat with a data collector in a room where they could observe and evaluate the patient monitoring scenarios undisturbed. Before each session, participants completed a demographic survey, watched a 6-minute instructional video on avatar-based monitoring, familiarized themselves with the traditional central station monitor interface, and received a study briefing explaining the required tasks. The Visual Patient Instructional Video, which explains the technology in more detail, is available as Supplementary Video 1. Each participant then evaluated four scenarios presented in random order showing each two critical and four healthy patients. These scenarios consisted of two identical scenarios shown to each participant in avatar-based and conventional form, hence the total of four scenarios. Participants were not aware of the two identical scenarios. After each scenario, participants recited the status of the vital signs of the critical patients aloud, and the data collector interrogated vital signs not actively mentioned. The vital signs had to be classified as either "too high", "normal", "too low" or "not perceived". Also, after each scenario, participants completed the National Aeronautics and Space Administration (NASA) Task Load Index (TLX) questionnaire, a validated measure of perceived workload[22,23]. We showed participants 10- and for 30-second scenarios to investigate effects of different viewing times. The participants watched either only the 10-second or only the 30-second scenarios. The conventional scenarios showed only the conventional display of the vital signs as numbers and curves. The avatar-based scenarios showed the animated avatar display in addition to the conventional display. To attain optimum realism, we highlighted abnormal vital signs in the scenarios. To attain equal conditions for all participants, we played scenarios as videos recorded using the app SimMon (Castle 2 Andersen ApS, Hillerød, Denmark) simulating a GE Datex Ohmeda monitor (General Electric Company, Boston, MA, USA). Figure 1 shows monitoring scenario examples of both technologies. Supplementary Video 2 shows all scenarios used in this study. We collected data for this study using an iPad-based data collection tool[24].

Scenarios

The critical patients in scenario 1 were a patient in septic shock and a patient with endotracheal tube obstruction. We simulated septic shock as pulse rate, respiratory rate and temperature too high, blood pressure, oxygen saturation and end-expiratory carbon dioxide concentration too low, other vital signs normal. We portrayed endotracheal tube obstruction as oxygen saturation, end-expiratory carbon dioxide concentration and tidal volume too low, other vitals normal.

The critical patients in scenario 2 were a patient in cardiopulmonary arrest and a patient with malignant hyperthermia. We simulated cardiopulmonary arrest as pulse rate, blood pressure, oxygen saturation, end-expiratory carbon dioxide concentration too low, ST-segment too high, other vital signs normal. We presented malignant hyperthermia as pulse rate, end-expiratory carbon dioxide concentration and body temperature too high, blood pressure too low, other vitals normal.

Outcome measures

The primary objective of this study was to compare the perceptual performance of anesthesia providers observing central station patient monitor scenarios with both technologies. Therefore, we compared the number of vital signs participants correctly identified with both monitoring technologies. A secondary objective was to compare the perceived workload during the task with both technologies.

Statistical analysis

We express distribution of variables as medians with interquartile range (IQR) regardless of normality. To assess normality, we used the Shapiro-Wilks test and visual inspection of quantile-quantile plots of dependent variables. To compare perceptive performance and perceived workload between avatar-based and number and waveform-based monitoring scenarios, we used paired t-test for normally distributed data or Wilcoxon matched-pairs signed-ranks test for non-normally distributed data. Median of difference are computed using the Hodges-Lehmann estimate and confidence intervals (CI) for median of difference are calculated by the Hodges-Lehmann method. Since the Wilcoxon signed-ranks test works with ranks, it is usually not possible to get a CI with exactly 95% confidence. If this is the case, we always present the precise rank dependent value of the CI. To assess differences between study sites for statistical significance, we used Mann-Whitney or Fisher's exact test. We used GraphPad PRISM 8.1.1 (GraphPad Software Inc., CA, U.S.A.) for statistical analysis and creation of figures. A p-value of less than 0.05 was considered to indicate statistical significance, and between 0.05 and 0.1 to indicate a tendency.

Sample size

We calculated the sample size for this study with the standard deviation of 0.81, which we found in a pilot study with six participants, and assumed the clinically relevant difference at one vital sign. At the specified standard deviation and for the assumed clinically relevant difference, the required sample size for a paired t-test with a power of 80% at a significance level of 5% is 8 participants. To detect a difference of one vital sign with the specified power at the 5% significance level in each center, for both scenarios, and both viewing durations, we had to include at least 16 participants per center, or 32 participants total, who each evaluated two scenarios.

Results

Table 1 shows the study and participant characteristics. The samples from the two centers showed no statistically significant differences regarding occupational groups, gender, age or anesthesia experience. We recruited 16 participants at USZ and 22 participants at KSW.

Outcome measures

Figure 2 compares the anesthesia providers' perceptual performance between avatar-based and conventional monitoring in the 10-second scenarios. Using avatar-based monitoring, anesthesia providers perceived a median of 11 (IQR 8 to 15) vital signs, compared to only 7 (IQR 4 to 9), using conventional monitoring, $p<0.001$, median of differences 5 vital signs (97.99% CI 0 to 7). Figure 3 compares the perceived workload in the 10-second scenarios. Using avatar-based monitoring, anesthesia providers had a lower median NASA TLX score of 67 (IQR 51 to 75), compared to 77 (IQR 51 to 84), using conventional monitoring, $p = 0.024$, median of differences 5 (97.99% CI 0 to 10). In the 30-second scenarios, the differences between the avatar and conventional monitoring were not statistically significant. Anesthesia providers perceived a median of 16 (IQR 13 to 18) vital signs with the avatar, vs. 15 (IQR 13 to 17), using conventional patient monitoring, $p = 0.055$. Likewise, NASA TLX scores did not differ in the more extended 30-second scenarios with a median score of 60 for both technologies, $p = 0.59$. Figures 4 and 5 show these results.

Discussion

Situation awareness errors may endanger patient safety, and therefore, maintaining an adequate situation awareness is an important non-technical skill of anesthesia providers[25]. This multicenter computer-based laboratory study focused on studying perception errors, which are the principal cause of situation awareness failures[3-6]. Anesthesia providers monitored multiple central monitor scenarios using an avatar-based virtual patient model and a conventional number- and waveform-based monitor. After an observation period, the computer screen darkened and participants had to recall patient status of the two critical patients shown in each scenario, and rate their perceived workload using the NASA Task-Load-Index questionnaire.

Participants' perceptive performance improved significantly in the 10-second avatar-based scenarios by a median of difference of 5 vital signs. Perceived workload also decreased significantly by a median of difference of 5 points in NASA TLX score, compared to the 10-second conventional scenario. These results for avatar-based monitoring of several patients at the same time, are similar to previous studies, which investigated the effects of avatar-based monitoring for monitoring one patient at a time and for monitoring with peripheral vision[19-21].

The fact that the improvement in perceptive performance in the 30-second scenarios was smaller, and not statistically significant, suggests that avatar-based monitoring might be especially helpful when looking at monitors in short glances, which reflects reality in clinical work[7].

The reduced perceived workload of participants with avatar-based monitoring is of particular relevance, since central monitors are commonly located in areas with a high interaction between the observer and their environment, e.g. co-workers, noise, visitors or phone-calls.[5] Increased workload is associated with stress, perception errors and consequently impaired decision-making, all jeopardizing patient safety[26]. In this context, researchers identified inattentional blindness as a common form of perception error[10,11,27]. This may especially occur in change detection and in unexpected events[9].

In addition to simplifying the presentation of monitoring information, as Visual Patient Technology does, there have been other attempts to improve users' situation awareness. One study, e.g., analyzed a vibro-tactile-belt display, which mapped and converted monitoring parameters and their changings into stimulation patterns[28]. Another study, which evaluated the potential of a head-worn display for multiple patient monitoring in supervising anesthetists, found improved situation awareness[29]. The emergence of these technologies represents a growing awareness of shortcomings of conventional monitoring[30].

Limitations

This study was conducted as a computer-based laboratory study and as such has some specific limitations. Most importantly, this study did not test any patient outcome measures and only tested the technology in an undisturbed and simulated environment, which excluded potential effects of distractions that could be present in a real environment. It is, therefore, unclear how the results would translate into a real operating room or intensive care unit environment. Also, workload was measured with the NASA Task-Load-Index. Although this is a validated and commonly used tool, there are other, more direct, measures of stress, which we did not assess in this study, e.g., participants’ heart rate variability or pupil dilation[31-33].

Strengths

This multicenter study found a clinically and statistically significant performance improvement in the 10-second scenarios with Visual Patient Technology. The variety of anesthesia providers included into this study, with different professional experience and positions, as well as age and sex, increases external validity.

Conclusions

This study provides empirical evidence that avatar-based monitoring (Visual Patient Technology) in a central monitor station, when monitoring multiple patients at the same time, improves perception of vital sign information and reduces perceived workload, especially, when the monitor observation is of short duration. The next studies with the avatar-based technology should be conducted in a real or high fidelity simulated environment to factor in the effects of distraction, and assess direct measures of stress.

Abbreviations

USZ University Hospital Zurich

KSW Cantonal Hospital Winterthur

IQR Interquartile Range

NASA National Aeronautics and Space Administration

TLX Task-Load-Index

Declarations

Ethics approval and consent to participate

This study was reviewed by the Cantonal Ethics Committee, University of Zurich, the responsible ethics committee for both study centers. The ethics committee issued a declaration of no objection. Reference Number 2017-00795, dated 23 October 2017. The participants took part voluntarily and signed a consent to the use of their data for research.

Consent for publication

Not applicable.

Availability of data and materials

The datasets generated and analyzed during this study are available from the corresponding author on reasonable request.

Competing interests

The authors DRS, CBN and DWT are in a Joint Development Agreement with Philips Healthcare (Koninklijke Philips N.V, Amsterdam, The Netherlands). Within the framework of this agreement, a product based on the Visual Patient concept will be developed. If successful, the authors CBN and DWT could receive royalties as inventors of the technology. The other authors have no competing interests regarding this manuscript.

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Authors' contributions

OG, JR, JP, MTG, DRS, CBN and DWT helped to design the study. JP, MTG, CBN and DWT helped to collect the data. OG, JR, CBN and DWT helped to analyze the data. OG, JR, MTG, DRS and DWT helped to write the article. All authors have read and approved the final manuscript.

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References

1 World Health Organization. Guidelines for Safe Surgery 2009. Geneva, Switzerland, 2009: World Health Organization

2 Endsley MR. Toward a Theory of Situation Awareness in Dynamic Systems. Hum factors 1995; **37:** 32-64

3 Schulz CM, Endsley MR, Kochs EF, Gelb AW, Wagner KJ. Situation awareness in anesthesia: concept and research. Anesthesiology 2013;118:729-42.

4 Endsley M, Jones, D. Designing for situation awareness: an approach to user-centered design.

Boca Raton, FL, USA: CRC Press Inc., 2011.

5 Fioratou E, Flin R, Glavin R, Patey R. Beyond monitoring: distributed situation awareness in anesthesia. Br J Anaesth 2010; **105:** 83-90

6 Schulz CM, Burden A, Posner KL, et al. Frequency and Type of Situational Awareness Errors Contributing to Death and Brain Damage: A Closed Claims Analysis. Anesthesiology 2017;127:326-37.

7 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:** 653-8

8 Loeb RG. Monitor surveillance and vigilance of anesthesia residents. Anesthesiology 1994; **80:** 527-33

9 Rensink RA. Change detection. Annu Rev Psychol 2002; **53:** 245-77

10 Ho AM, Leung JYC, Mizubuti GB, et al. Inattentional blindness in anesthesiology: A simulation study. J Clin Anesth 2017; **42:** 36-9

11 Greig PR, Higham H, Nobre AC. Failure to perceive clinical events: an under-recognised source of error. Resuscitation 2014; **85:** 952-6

12 Simons DJ. Attentional capture and inattentional blindness. Trends Cogn Sci 2000; **4:** 147-55

13 Mack A. Inattentional Blindness: Looking Without Seeing. Curr Dir Psychol Sci 2003; **12:** 180-4

14 Mack A, Pappas Z, Silverman M, Gay R. What we see: inattention and the capture of attention by meaning. Conscious Cogn 2002; **11:** 488-506

15 Jungk A, Thull B, Hoeft A, Rau G. Ergonomic evaluation of an ecological interface and a profilogram display for hemodynamic monitoring. J Clin Monit Comput 1999; **15:** 469-79

16 Jungk A, Thull B, Hoeft A, Rau G. Evaluation of two new ecological interface approaches for the anesthesia workplace. J Clin Monit Comput 2000; **16:** 243-58

17 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 Inform Assoc 2006;**13**:635-642

18 Drews FA, Westenskow DR. The right picture is worth a thousand numbers: data displays in anesthesia. Hum factors 2006; **48:** 59-71

19 Tscholl DW, Handschin L, Neubauer P, et al. Using an animated patient avatar to improve perception of vital sign information by anesthesia professionals. Br J Anaesth 2018; **121:** 662-71

20 Tscholl DW, Weiss M, Handschin L, Spahn DR, Nöthiger CB. User perceptions of avatar-based patient monitoring: a mixed qualitative and quantitative study. BMC Anesthesiol 2018; **18:** 188

21 Pfarr J, Ganter MT, Spahn DR, Nöthiger CB, Tscholl DW. Avatar-based patient monitoring with peripheral vision. J Med Internet Res 2019 Jul 17;21(7):e13041.

22 Hart SG, Stavenland LE. Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. In: Hancock PA, Meshkati N, eds. Human Mental Workload: Elsevier, 1988; 139-83

23 Hart S. Nasa-Task Load Index (Nasa-TLX); 20 Years Later. Proc Hum Factors Ergon Soc Annu Meet 2006; Vol 50, Issue 9

24 Tscholl DW, Weiss M, Spahn DR, Noethiger CB. How to Conduct Multimethod Field Studies in the Operating Room: The iPad Combined With a Survey App as a Valid and Reliable Data Collection Tool. JMIR Res Protoc 2016; **5:** e4

25 Gaba DM, Howard SK, Small SD. Situation awareness in anesthesiology. Hum factors 1995; 37: 20-31

26 Webster CS, Weller JM. Self-reported ratings appear to be the best for workload measurement. BMJ Simul Technol Enhanc Learn 2018; **4:** 108-9

27 Simons DJ, Chabris CF. Gorillas in our midst: sustained inattentional blindness for dynamic events. Perception 1999; **28:** 1059-74

28 Dosani M, Hunc K, Dumont GA, et al. A vibro-tactile display for clinical monitoring: real-time evaluation. Anesth Analg 2012; **115:** 588-94

29 Schlosser PD, Grundgeiger T, Sanderson PM, Happel O. An exploratory clinical evaluation of a head-worn display based multiple-patient monitoring application: impact on supervising anesthesiologists' situation awareness. J Clin Monit Comput 2019 Feb 5.

30 Tscholl DW, Handschin L, Rossler J, Weiss M, Spahn DR, Nothiger CB. It's not you, it's the design - common problems with patient monitoring reported by anesthesiologists: a mixed qualitative and quantitative study. BMC Anesthesiol 2019; **19:** 87

31 Casner SM, Gore B. Measuring and Evaluating Workload: A Primer 2010: NASA Ames Research Center, Moffett Field, CA

32 Yang X, Kim JH. Measuring Workload in a Multitasking Environment Using Fractal Dimension of Pupil Dilation. Int J Hum Comput Interact. 2018: 1-10

33 Aasman J, Mulder G, Mulder LJ. Operator effort and the measurement of heart-rate variability. Hum factors 1987; **29:** 161-70

Tables

Table 1: Study and participant characteristics.

	KSW	USZ	p-value
Study duration in days (period)	12 (September 24th 2018 – October 5th 2018)		
Total number of participants	22	16	
Number of senior anesthetists (%)	6 (27%)	4 (24%)	p>0.99
Number of resident anesthetists (%)	7 (32%)	6 (38%)	p=0.74
Number of subspecialized nurse anesthetists (%)	9 (41%)	6 (38%)	p>0.99
Number of female/male participants (%)	12 (55%) / 10 (45%)	9 (56%) / 7 (44%)	p>0.99
Age of participants in years (%)	25 – 34: 7 (32) 35 – 44: 9 (41) 45 – 54: 5 (23) 54 – 65: 1 (4)	25 – 34: 9 (56) 35 – 44:6 (38) 45 – 54: 0 (0) 54 – 65: 1 (6)	p=0.084
Anesthesia experience of participants in years (%)	1 – 5: 5 (23) 5 – 10: 4 (18) > 10: 13 (59)	1 – 5: 8 (50) 5 – 10: 4 (25) > 10: 4 (25)	p=0.21

Figures

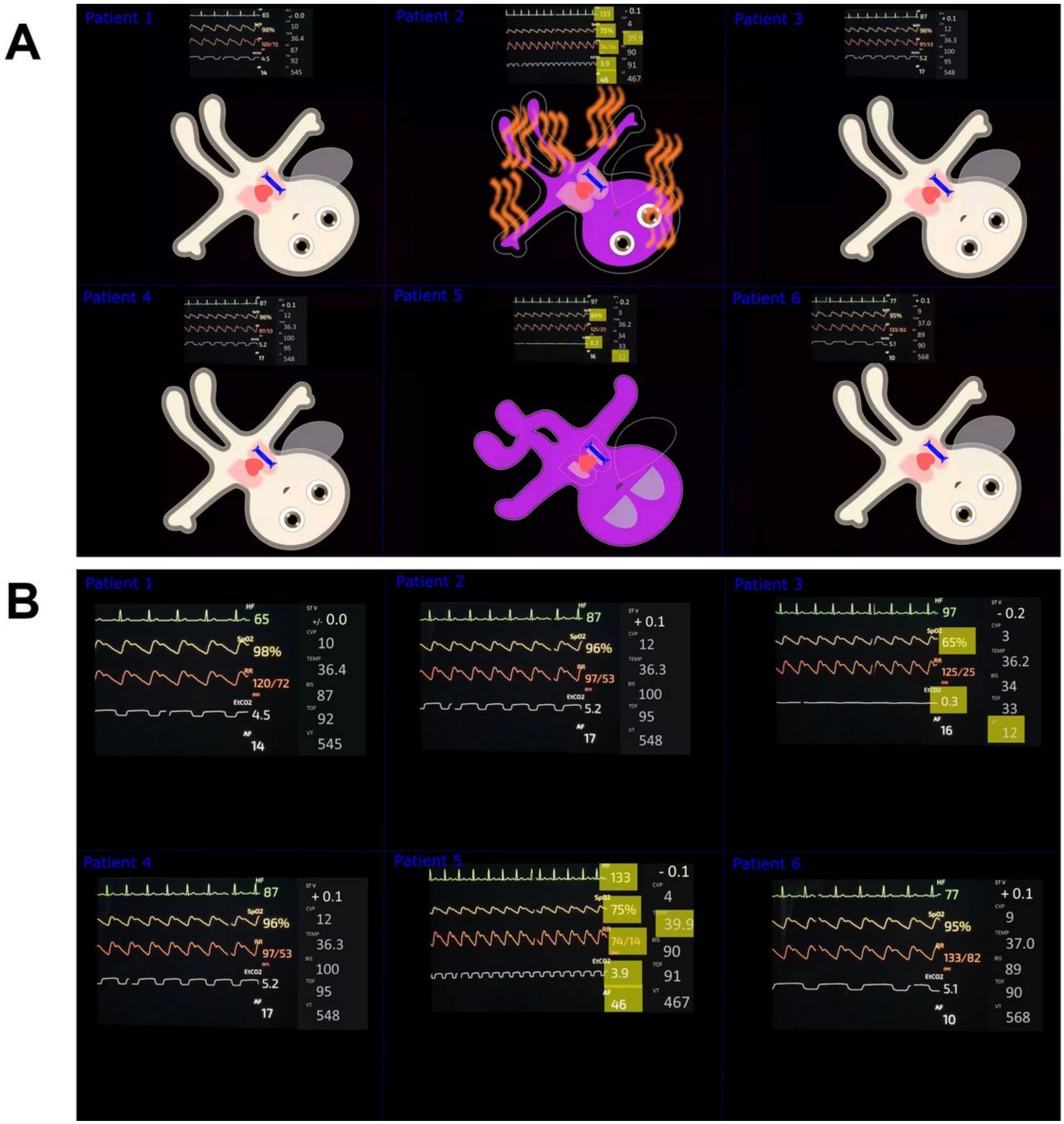

Figure 1

Scenario 1 showing a critical patient in septic shock and another patient with an endotracheal tube obstruction. (A) Avatar-based presentation. (B) Conventional, number and wave-form presentation.

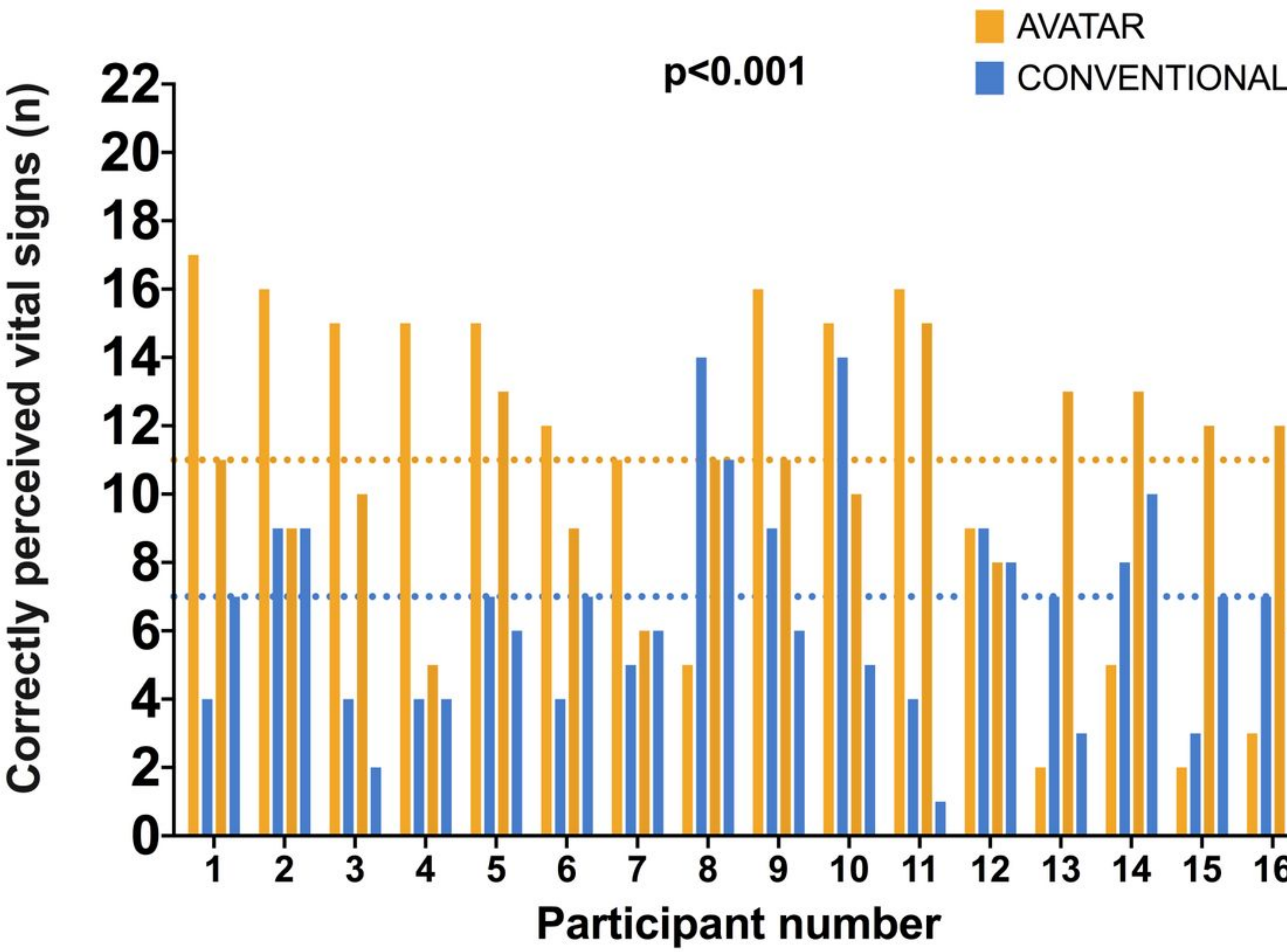

Figure 2

Perceptive performance in the 10-second scenarios. Dotted line is the median number of correctly perceived vital signs, which was 11 with avatar-based monitoring and 7 with conventional monitoring ($p < 0.001$).

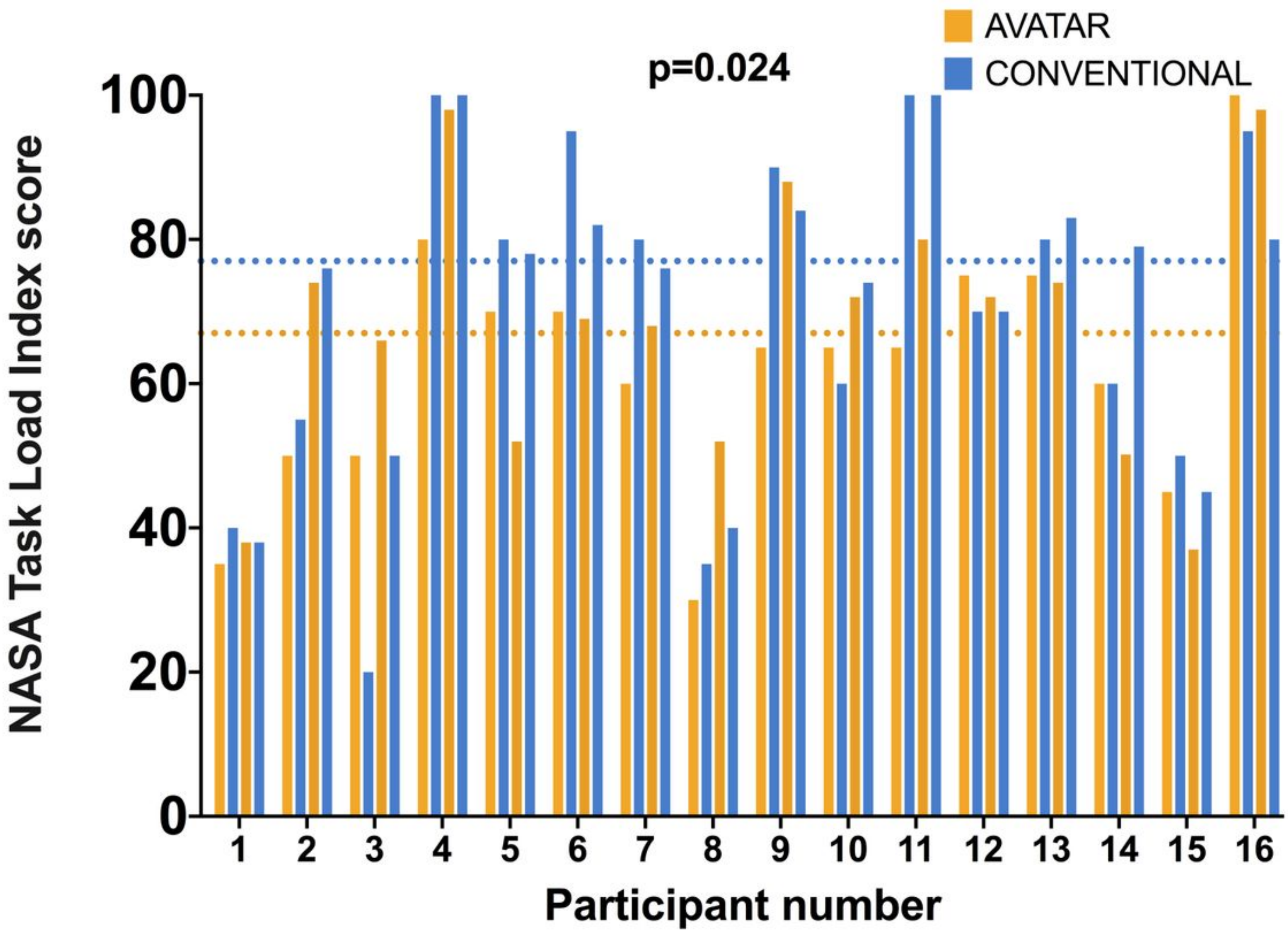

Figure 3

Perceived workload in the 10-second scenarios. Dotted line is the median NASA-TLX score, which was 67 with avatar-based monitoring and 77 with conventional monitoring (p = 0.024).

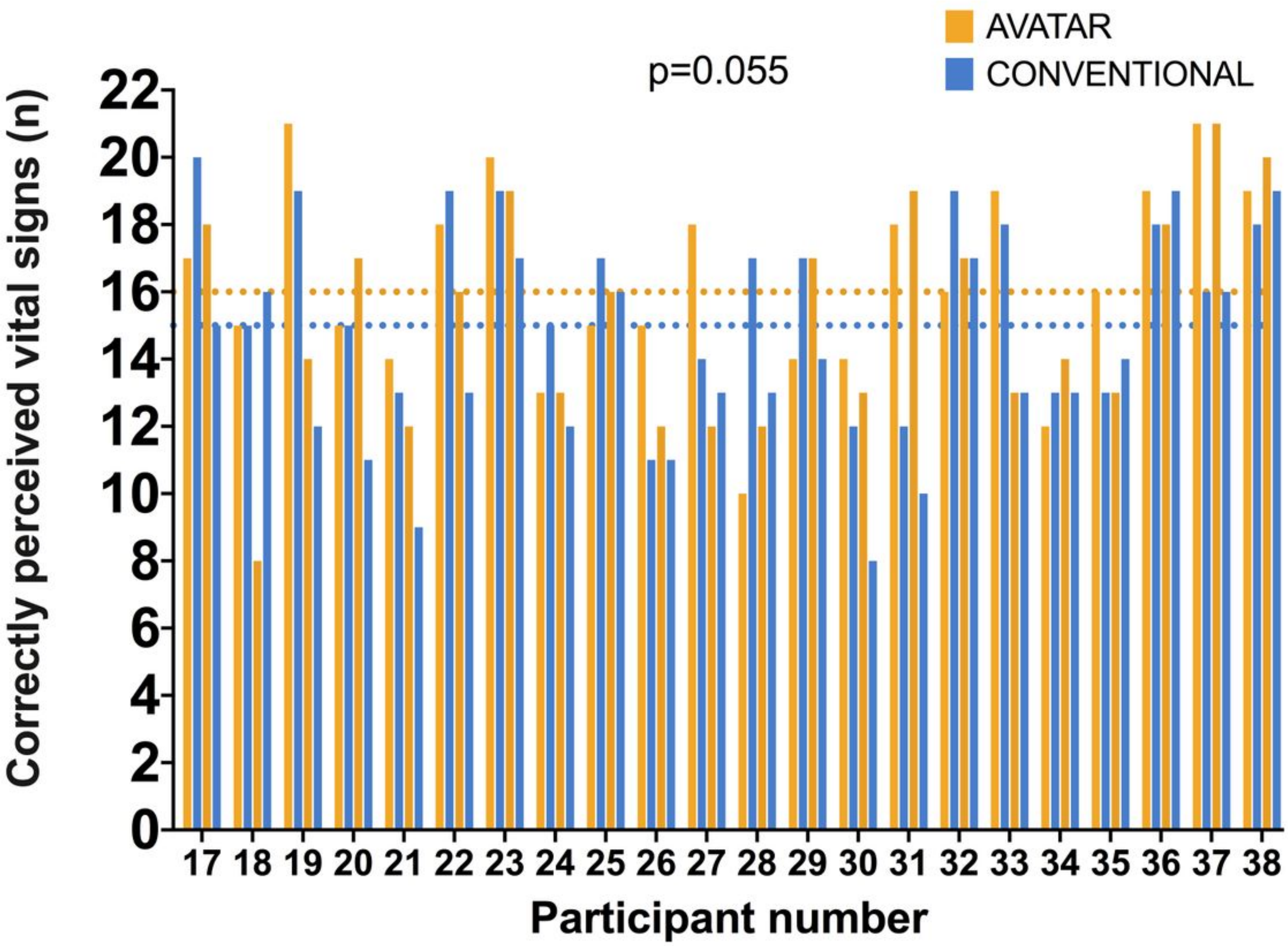

Figure 4

Perceptive performance in the 30-second scenarios. Dotted line is the median number of correctly perceived vital signs, which was 16 with avatar-based monitoring and 15 with conventional monitoring (p = 0.055).

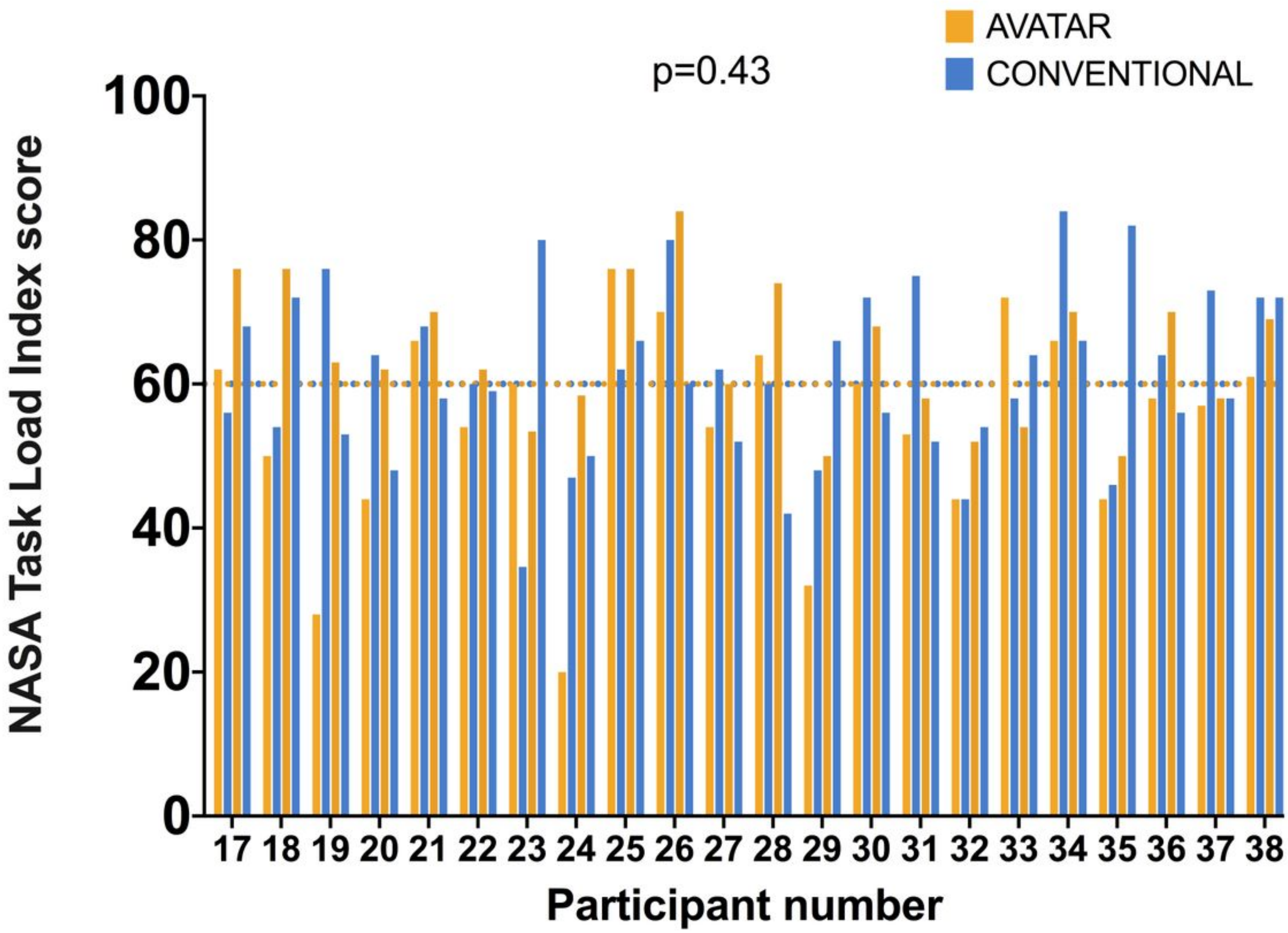

Figure 5

Perceived workload in the 30-second scenarios. Dotted line is the median NASA-TLX score, which was 60 with avatar-based monitoring and also 60 with conventional monitoring (p = 0.59).

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- SupplementaryVideo2.mp4
- SupplementaryVideo1.mov