

Monitoring with Head-Mounted Displays in General Anesthesia: A Clinical Evaluation in the Operating Room

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BACKGROUND: Patient monitors in the operating room are often positioned where it is difficult for the anesthesiologist to see them when performing procedures. Head-mounted displays (HMDs) can help anesthesiologists by superimposing a display of the patient's vital signs over the anesthesiologist's field of view. Simulator studies indicate that by using an HMD, anesthesiologists can spend more time looking at the patient and less at the monitors. We performed a clinical evaluation testing whether this finding would apply in practice.

METHODS: Six attending anesthesiologists provided anesthesia to patients undergoing rigid cystoscopy. Each anesthesiologist performed 6 cases alternating between standard monitoring using a Philips IntelliVue™ MP70 and standard monitoring plus a Microvision Nomad™ ND2000 HMD. The HMD interfaced wirelessly with the MP70 monitor and displayed waveform and numerical vital signs data. Video was recorded during all cases and analyzed to determine the percentage of time, frequency, and duration of looks at the anesthesia workstation and at the patient and surgical field during various anesthetic phases. Differences between the display conditions were tested for significance using repeated-measures analysis of variance.

RESULTS: Video data were collected from 36 cases that ranged from 17 to 75 minutes in duration (median 31 minutes). When participants were using the HMD, compared with standard monitoring, they spent less time looking toward the anesthesia workstation (21.0% vs 25.3%, $P = 0.003$) and more time looking toward the patient and surgical field (55.9% vs 51.5%, $P = 0.014$). The HMD had no effect on either the frequency of looks or the average duration of looks toward the patient and surgical field or toward the anesthesia workstation.

CONCLUSIONS: An HMD of patient vital signs reduces anesthesiologists' surveillance of the anesthesia workstation and allows them to spend more time monitoring their patient and surgical field during normal anesthesia. More research is needed to determine whether the behavioral changes can lead to improved anesthesiologist performance in the operating room. (Anesth Analg 2010;110:1032–8)

Human factors issues associated with standard patient monitors used in anesthesia are well documented.^{1,2} The monitors are often located in an awkward position, away from the patient, so that the anesthesiologist cannot monitor the patient's clinical signs while keeping the vital signs within view. Furthermore, the anesthesiologist may be unable to see the monitor when performing physically constraining tasks such as laryngoscopy, drawing up drugs, or repositioning the patient. Auditory alarms are intended to prevent

the anesthesiologist from missing important changes on the monitor, but alarms are often false, uninformative, difficult to distinguish, or are sometimes turned off.^{3,4}

One approach to solving these problems is to use an advanced monitoring display that provides the anesthesiologist with continuous information, removing the need to review information repeatedly on the visual monitor.⁴ The audible pulse oximetry tone is an example of such a display because it conveys the patient's oxygen saturation, heart rate, and rhythm, without the anesthesiologist having to review the monitor. Given the success of audible pulse oximetry, researchers have investigated presenting other vital signs using auditory, vibrotactile, or head-mounted display (HMD) technology.⁵

HMDs superimpose a visual information display over their wearers' field of view.⁶ They are similar to the head-up displays often used in aviation that allow pilots to detect unexpected changes to flight instrumentation faster than with traditional "head-down" cockpit displays.^{7,8} Several authors have proposed that the benefits found with head-up displays may also apply to HMDs in anesthesia.^{3,4,9–12} HMDs could be a solution to the ergonomic issues associated with the location of patient monitors by letting the anesthesiologist perform physically constraining

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Accepted for publication December 22, 2009.

Supported by Australian Research Council Discovery Project grant ARC DP0559504 (to PMS, M. Watson, and WJR) and an Australian Postgraduate Award (for DL).

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DOI: 10.1213/ANE.0b013e3181d3e647

tasks while continuing to monitor the patient. In contrast to traditional “slave” monitoring displays, the HMD does not require the anesthesiologist to look away from the primary task to see the information presented. Furthermore, the HMD is always available even in locations where both the primary and slave displays are out of view.

Monitoring with HMDs has been evaluated in both clinical and simulated operating room (OR) environments.^{4,13} After briefly experiencing the HMD in the OR, anesthesiologists from 2 independent clinical studies reported that the HMD had potential despite its technological limitations.^{10*} Simulator-based studies have indicated that an HMD allows anesthesiologists to spend more time focusing on the patient and less time looking at the monitor and anesthesia workstation.^{14,15} Furthermore, anesthesiologists using the HMD when they were busy and physically constrained detected changes in their simulated patient’s vital signs faster than with a standard monitor.^{15†} Similar benefits have also been found with surgeons in simulated environments.^{16,17} Finally, anesthesiologists report that they detect vital signs changes faster with an HMD compared with a standard monitoring display.^{15,18}

The 2 previously reported clinical HMD evaluations^{10*} had serious limitations. First, 1 study was reported in an abstract* and does not seem to have been published in a peer-reviewed journal. Second, in both studies, there were no objective measures of anesthesiologists’ performances or behavioral changes when using the HMD nor were there control conditions for comparison. Third, no waveforms were presented on the HMD in 1 study,¹⁰ and no CO₂ information in the other.* Fourth, the HMD was used for a short time; participants experienced only 1 case¹⁰ or 1 induction* with the HMD. Finally, the participants were tethered to the anesthesia workstation by a connecting cable for the HMD unit, and so were not free to move about the OR.^{10*}

Although simulator-based studies have demonstrated benefits for monitoring with HMDs, there have been no controlled studies to determine whether the results from the simulator will generalize to the clinical environment.

We report the results of a prospective, controlled clinical evaluation of monitoring with HMDs. Our aim was to examine whether the HMD would free the anesthesiologist’s visual attention from the anesthesia workstation and allow him or her to spend more time looking at the patient, as was found in simulator-based studies.^{14,15}

METHODS

Participants

This study received Human Research and Ethics Committee approvals from the Royal Adelaide Hospital (RAH) and The University of Queensland, and was registered with the Australian New Zealand Clinical Trials Registry

*Via DK, Kyle RR, Geiger PG, Mongan PD. A head mounted display of anesthesia monitoring data is of value and would be used by a majority of anesthesia providers. *Anesth Analg* 2002;95:S132.

†Via DK, Kyle RR, Kaye RD, Shields CH, Dymond MJ, Damiano LA, Mongan PD. A head mounted display of anesthesia monitoring data improves time to recognition of crisis events in simulated crisis scenarios. Proceedings of Society for Technology in Anesthesia 2003 Annual Meeting. Available at: http://www.anestech.org/media/Publications/Annual_2003/sta112.html.



Figure 1. An anesthesiologist manually ventilates a patient with a bag and mask during induction, while simultaneously monitoring the patient’s vital signs using the head-mounted display (HMD). The HMD uses a single transparent monocle over the anesthesiologist’s right eye to superimpose information over their field of view (Fig. 2). The battery pack and interfacing computer are contained within the backpack worn by the participant and a head-mounted camera records the anesthesiologist’s direction of gaze (Fig. 3).

(ACTRN12608000245392). Six RAH anesthesiologists volunteered for the study and provided written consent. The selection criteria included board certification (attending anesthesiologists), regular engagement in urology OR lists, and prior participation in at least 1 simulator-based HMD study conducted at the RAH over the previous 2 years.^{15,18}

Design

A 2 (display) × 3 (trial) repeated-measures design was used. Display referred to the monitoring technologies available to participants: the control condition was the standard patient monitor, and the HMD condition was the standard patient monitor plus the HMD (Fig. 1). Trial referred to the first, second, or third case performed by participants for each condition. Each participant provided anesthesia to 6 patients, corresponding to the 6 combinations of the experimental design.

The dependent variables were the percentage, frequency, and duration of participants’ head turns toward the anesthesia workstation and toward the patient/surgical field (6 variables in total). Percentage was the amount of time that participants spent looking at the anesthesia workstation or at the patient/surgical field as a percentage of the total case duration. Frequency measured the number of head turns per minute. Duration measured the mean time in seconds that participants spent looking toward the anesthesia workstation or patient/surgical field for each head turn. The anesthesia workstation included the standard patient monitor, ventilator, gas flows, volatile anesthetic dials, and electronic record-keeping system. The patient/surgical field included the patient, operating table, IV stands, surgical field, and the cystoscope monitor.

Case Selection

Cases in the urology theater were selected on the basis of specific inclusion and exclusion criteria that were intended to minimize the variability between cases and therefore

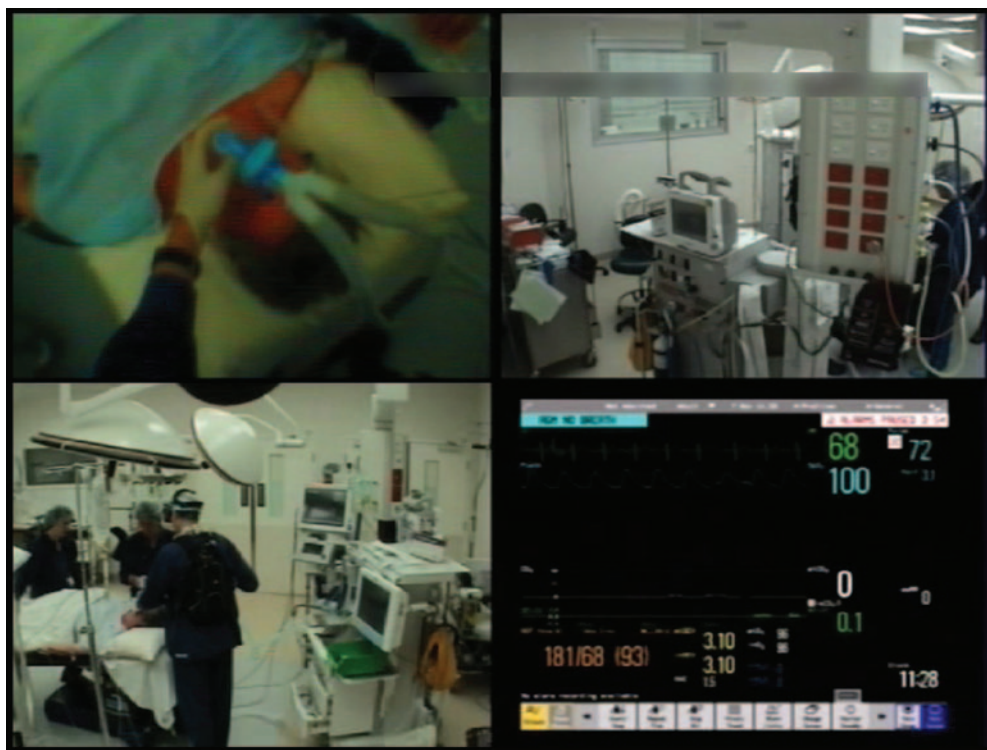


Figure 3. Screen capture of the video data recorded for the study showing the same scene as in Figure 1. Clockwise from top left: view from a head-mount camera worn by the participant, field camera showing the drug cart and anesthetic area, the Philips IntelliVue™ MP70 patient monitor display, and a field camera showing the patient and anesthetic area.

when the last monitor was removed (e.g., capnography). The participants' monitoring behavior was coded from the video data in 3 steps by 1 experienced coder (DL) using a custom software tool (as in 2 prior HMD studies¹⁵). First, changes in where participants were looking as each case unfolded were recorded under 1 of 3 gaze location categories: anesthesia workstation (including gas and ventilator controls, patient monitors, and the electronic record-keeping system), patient/surgical field (including patient head and airway, IV line, surgical draped area, surgeon, and cystoscope display), and other (including reading materials, OR staff away from the surgical field, and drug cart). Second, each case was divided into 3 main phases: induction (from when the first drug was administered), maintenance (starting at onset of surgery), and emergence (from the cessation of volatile anesthetic until all monitoring was removed). Induction was further subdivided into drugs (when the first drug was administered), LMA placement (when the anesthesiologist took the mask from the anesthetic nurse), and draping (when the anesthesiologist helped reposition the patient). Finally, the percentage, frequency, and duration metrics were calculated from the coded head-turning data for each anesthetic phase.

Analysis

Differences in the percentage, frequency, and duration metrics from the head-turning data were independently tested for significance with Statistica™ 8 (StatSoft, Tulsa, OK) using a repeated-measures analysis of variance for each measure with $\alpha = 0.05$, 2-tailed. The factors were display (control, HMD) \times trial (first, second, third) \times phase

(induction [drugs], induction [LMA placement], induction [draping], maintenance, emergence) \times gaze location (anesthesia workstation, patient/surgical field). Planned comparisons were used to test the differences between display conditions independently for each gaze location (averaging over the 5 phases).

For questionnaire responses, if a question was asked in both display conditions, then differences in mean Likert scale values between the 2 conditions were tested for significance with Statistica using *t* tests of dependent samples with $\alpha = 0.05$, 2-tailed. Responses to questions that did not have a control condition baseline were tested for significance with Statistica using *t* tests against a single sample, 4 (neutral response), with $\alpha = 0.05$, 2-tailed. For analyses of postsession questionnaires where participants performed 3 cases in each display condition, responses for each display were averaged.

RESULTS

Monitoring Behavior

The duration of cases ranged from 17 to 75 minutes with a median of 31 minutes. The frequency of anesthesiologists' looks toward the anesthesia workstation and patient/surgical field, as well as the percentage of time they looked at each, and the average duration of each look were calculated from 16,342 head turns coded in 22 hours of video (Table 1).

For the percentage of time the anesthesiologist was looking toward an object, there were main effects of phase ($P < 0.001$) and gaze location ($P < 0.001$) but no effect of

Table 1. Monitoring Behavior Variables (Percentage, Frequency, Duration) Averaged Across All Participants for Each Direction of Gaze, Display Condition, and Phase

Variable	Direction of gaze	Display	Induction (drugs)	Induction (LMA placement)	Induction (draping)	Maintenance	Emergence	Mean of all phases
Percentage	Anesthesia workstation	Control	23.4% (10.4%)	24.5% (11.9%)	26.5% (12.6%)	27.6% (13.6%)	24.3% (12.6%)	25.3% (12.1%) ^a
	Patient/surgical field	Control	61.6% (13.0%)	68.6% (13.4%)	34.8% (16.5%)	34.8% (14.1%)	57.9% (14.5%)	51.5% (19.9%) ^a
		HMD	67.4% (10.9%)	72.8% (9.7%)	37.7% (20.3%)	37.4% (15.1%)	64.1% (13.4%)	55.9% (20.8%) ^a
Frequency (/min)	Anesthesia workstation	Control	4.3 (1.5)	4.5 (1.6)	3.7 (1.0)	3.8 (0.9)	4.0 (1.3)	4.1 (1.3)
	Patient/surgical field	Control	5.5 (1.6)	5.6 (1.8)	3.9 (1.9)	4.2 (1.5)	5.8 (2.0)	5.0 (1.9)
		HMD	5.0 (1.5)	5.8 (1.6)	4.3 (2.1)	4.1 (1.2)	5.3 (1.6)	4.9 (1.7)
Duration (s)	Anesthesia workstation	Control	3.4 (1.2)	3.5 (1.9)	4.3 (1.9)	4.3 (1.5)	3.7 (1.9)	3.8 (1.7)
	Patient/surgical field	Control	8.0 (5.9)	9.6 (10.7)	5.9 (3.1)	5.2 (2.5)	6.6 (2.7)	7.1 (6.0)
		HMD	9.1 (3.9)	8.3 (3.3)	6.0 (5.5)	5.7 (2.8)	7.9 (2.7)	7.4 (3.9)

sd s are shown in parentheses.

LMA = laryngeal mask airway.

^a Difference between head-mounted display (HMD) and control condition across all phases significant at $P < 0.05$.

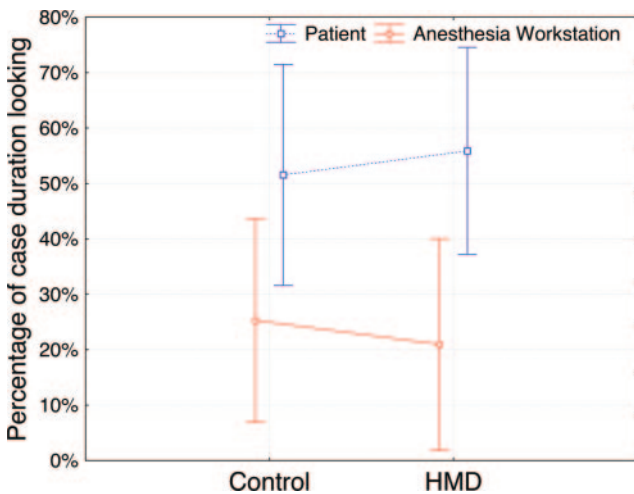


Figure 4. The percentage of time participants spent looking toward the anesthesia workstation and patient/surgical field for both display conditions. Participants with the head-mounted display (HMD) spent a smaller percentage of time looking toward the anesthesia workstation ($P = 0.003$) and a larger percentage of time looking toward the patient/surgical field ($P = 0.014$) than in the control condition. Error bars indicate 95% confidence intervals.

display or trial (Fig. 4). Moreover, there was a significant interaction between phase and gaze location ($P < 0.001$) and between display and gaze location ($P < 0.001$). Planned comparisons showed that participants with the HMD spent less time looking at the anesthesia workstation (21.0% vs 25.3%, $P = 0.003$) and more time looking at the patient/surgical field (55.9% vs 51.5%, $P = 0.014$), than in the control condition.

For the frequency of head turns toward an object, there were main effects of phase ($P = 0.018$) and gaze location ($P = 0.011$), a significant interaction between phase and gaze location ($P = 0.002$), but no effects of display or trial. Participants looked more frequently toward the patient/surgical field (5.0 head turns/min) than toward the anesthesia workstation (3.9 head turns/min).

For the duration of looks toward an object, there was a main effect of gaze location ($P = 0.003$) and a significant interaction between phase and gaze location ($P = 0.019$),

Table 2. Means of Participants' Responses to Questionnaires on a Likert Scale from 1 to 7, Where 1 = Very Difficult/Slowly/Not Useful/etc., 4 = Neutral, and 7 = Very Easy/Quickly/Useful

	Control	HMD
Postsession questionnaire		
How easy was it to monitor the patient?	5.6 (1.1)	5.8 (0.9)
How quickly did you detect abnormal changes?	5.3 (1.1)	5.6 (0.9)
How useful was the information on the standard patient monitor?	6.2 (0.6)	5.2 (1.0) ^a
How useful was the information on the anesthesia machine?	5.9 (0.5)	5.7 (0.7)
How useful was the information presented on the HMD?	N/A	5.4 (1.0) ^a
How comfortable was it to read information on the HMD?	N/A	4.9 (1.2)
How easy was it to monitor vital signs on the HMD?	N/A	5.1 (1.3)
Postexperiment questionnaire		
Was there enough information on the HMD? (7 = too much)		4.3 (1.0)
How useful was the HMD in this experiment?		4.5 (1.0)
How useful would the HMD be in general?		4.9 (1.1)
Did you receive enough training with the HMD?		4.2 (0.4)
How satisfied were you with the HMD?		4.8 (1.2)

sd s are shown in parentheses.

^a Difference between head-mounted display (HMD) condition and control/neutral significant at $P < 0.05$.

but no effect of display, trial, or phase. Participants looked at the anesthesia workstation for 3.7 seconds per head turn on average and 7.2 seconds per head turn toward the patient/surgical field.

Two critical events occurred during the study: there was an episode of regurgitation during 1 control case and another episode of regurgitation during an HMD case. Both cases were included in the overall analysis. There were not enough cases for meaningful statistical comparison of the effect of HMD use on behavior during critical events (but a descriptive analysis of the 2 events was performed²⁰).

Questionnaires

Table 2 shows the participants' responses on Likert scales in postsession and postexperiment questionnaires. There were no significant differences in participants' responses between the 2 display conditions for perceived ease of monitoring, speed of abnormality detection, or usefulness of the anesthesia machine. However, participants rated the standard patient monitor as being less useful when they used the HMD (5.2 vs 6.2, $P = 0.030$).

On a Likert scale from 1 (useless) to 7 (very useful), participants rated the HMD as being moderately useful (5.4 vs neutrality at 4.0, $P = 0.013$). There was a tendency toward rating the HMD as comfortable to read (4.9 vs neutrality at 4.0, $P = 0.085$) and easy to monitor (5.1, $P = 0.065$), which did not reach significance with this sample size. The responses to postexperiment questionnaires were not significantly different from neutral (4.0), indicating that participants did not have significantly positive or negative views about the HMD.

In questionnaire free-form responses, participants indicated that they liked being able to monitor vital signs with the HMD anywhere in the OR without having to turn around, but disliked wearing the experimental equipment because of its weight and bulk. Issues with HMD use included difficulties reading information presented on the display (focusing and visual interference) and maneuvering tight spaces with the experimental equipment. Participants also noted that displaying the NIBP cycle state, time until next blood pressure sample, and tidal volumes on the HMD would have been useful.

CONCLUSIONS

The head-turning results suggest that HMDs could help anesthesiologists free their attention from the patient monitor and focus on monitoring the patient's clinical signs and the surgical field. When participants wore the HMD, they spent less time looking toward the anesthesia workstation and more time looking toward the patient and surgical field. The increase in time spent looking at the patient and surgical field, at the monitor's expense, is consistent with findings from a full-scale simulation-based study using the same device.¹⁵

Participants considered the HMD to be moderately useful. When the HMD was available, the standard patient monitor was considered relatively less useful than when only standard monitoring was available. In contrast, the anesthesia machine presented information not available on the HMD, and therefore, it was considered equally useful in both display conditions.

The HMD did not change how often participants looked in a certain direction or for how long. This result suggests that although the HMD reduced the total amount of time that anesthesiologists looked at the anesthesia workstation, it did not dramatically alter their pattern of head turning during routine monitoring, such as by completely eliminating the need to look at the workstation. The reduction in time spent looking toward the workstation with the HMD can be compared with the results of other studies in which the effect of variables relating to major changes in practice such as expertise,²¹ fatigue,²² and intraoperative reading²³ are examined. Although participants' gaze locations are

coded differently in each study, some comparisons are possible. In this experiment, the HMD provided a similar benefit to that of expertise in redirecting the anesthesiologists' looks away from the anesthesia workstation and toward the patient and surgical field.²¹ In contrast, a time-consuming activity such as intraoperative reading does not change the amount of time anesthesiologists spend observing monitors or the surgical field,²³ whereas the HMD does change the scanning patterns to some degree.

During situations that have a demonstrated effect on anesthesiologists' monitoring behaviors and vigilance, however, HMDs may provide other benefits. Novice anesthesiologists spend more time observing monitors compared with experienced anesthesiologists,²¹ and when anesthesiologists are fatigued, they spend more time observing the monitors, patient, and surgical field than when they are rested.²² When the anesthesiologist is busy during periods of high workloads,²¹ teaching residents,²⁴ or using transesophageal echocardiography,²⁵ they respond to changes on the patient monitor more slowly. However, these situations were not investigated in this study; therefore, further research would be needed to determine whether HMD use would reduce event detection times.²⁶

Finally, few studies have been able to demonstrate that a novel anesthesia monitoring display is clinically effective.^{4,27,28} However, this study found that the HMD induced a behavioral change in anesthesiologists' monitoring patterns comparable with that observed in a controlled simulation study.¹⁵

Limitations

This study was limited by a number of factors. First, when participants were using the HMD, the increase in time spent looking toward the patient and surgical field with the HMD was relatively small (4.4% difference), and their time looking at the anesthesia workstation was still substantial (21.0% of the case). However, these statistics may underrepresent the difference in monitoring patterns as a result of HMD use. Even with an HMD, the anesthesiologist would still need to look at the anesthesia workstation to perform tasks (e.g., adjusting gas flows) or monitor information not available on the HMD (e.g., ventilator settings and documentation). Furthermore, the HMD allows anesthesiologists to monitor the vital signs during tasks in which it would be otherwise impossible or impractical to see the patient monitor (e.g., laryngoscopy), but this would not be reflected in the behavioral statistics.

Second, the weight and bulk of the head-mount and backpack equipment was a major concern for participants. Technological improvements to superimposed information displays should result in smaller and less obtrusive devices.²⁹

Third, despite participants' prior involvement in HMD studies, they experienced the HMD for only 2 hours in total during the study. They may not have had sufficient time to break their existing monitoring habits and develop new strategies that make specific use of the HMD.

Fourth, the number of participants in the study was relatively small, but the study gained power by examining HMD and non-HMD management in the same anesthesiologists.

Finally, the cases selected for the study involved stable patients requiring relatively simple anesthetics and a basic level of monitoring (e.g., no invasive blood pressure monitoring). Although the behavioral analyses investigated the effect of HMDs on anesthesiologists' monitoring behaviors in the OR, they did not investigate how HMDs might affect the management of clinical events and crises.²⁰ The HMD may be more effective in cases in which the patient's condition is unstable or could deteriorate rapidly.

Future Research

More research is needed to determine which types of data should be presented on the HMD, whether further exposure to the HMD leads to more marked behavioral changes, and whether the behavioral changes resulting from HMD use can lead to improved anesthesiologist performance in the OR or improved patient outcomes.³⁰ ■■

ACKNOWLEDGMENTS

The authors thank the 6 anesthesiologists who participated for their time and feedback, and the medical staff and patients at the Royal Adelaide Hospital (RAH) who consented to being recorded on video for the study. They also thank Nicole Zweck and her nursing, anesthetic, and surgical colleagues from RAH Theater 7 for accommodating the experiment. They acknowledge the help of Matthew Thompson (The University of Queensland) in setting up the audiovisual equipment, Craig Todd, and his Biomedical Engineering colleagues (RAH) for technical advice and assistance preparing equipment. Finally, they also acknowledge the help of Terrence Leane and Edward Murphy (RAH) for assistance with portable patient monitors during the study.

DISCLOSURE

David Liu reports that he is currently a Visiting Graduate Student at the University of Utah under the supervision of Dwayne Westenskow, section Editor for Technology, Computing, and Simulation for the journal.

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