Monitor Surveillance and Vigilance of Anesthesia Residents

Robert G. Loeb, M.D.∗

Background: Anesthesia residents take longer to detect changes in electronically monitored data during the induction phase of anesthesia than during the maintenance phase. This study was performed to investigate the reasons for this delay and to validate a method of measuring vigilance.

Methods: The activity of ten residents was studied during 73 surgical procedures. Data were collected during three 15-min periods from each case: induction, starting with application of the electrocardiograph; maintenance, an arbitrary period between induction and emergence; and emergence, ending with detachment of the electrocardiograph. Vigilance was measured as the time taken to detect a change, from normal to abnormal, of an artificial parameter displayed on the physiologic monitor (response time). An observer simultaneously recorded each time that the resident looked toward the monitors.

Results: Vigilance to the monitor display was less during induction and emergence than during maintenance (P < 0.005). Residents spent less total time watching monitors during induction than during maintenance (P < 0.005), and the duration of each monitor observation was shorter (P < 0.0005). Anesthesia residents usually looked at the monitors several times before detecting the abnormal value. The measure of anesthesia vigilance correlated with independent measures of monitor watching time and frequency.

Conclusions: The results suggest that during induction of anesthesia, which is a period of high anesthesiologist workload, residents glance toward monitors to gather data rather than scan displays. The results help to validate the method for measuring anesthesia vigilance. (Key words: Anesthesiologists; performance. Monitoring, vigilance; measures. Human factors (ergonomics).)

CONTINUAI surveillance is an important element of anesthesia vigilance.† To detect impending problems and maintain a state of clinical awareness, the anesthesiologist must repeatedly look at the patient, the surgical field, and the delivery and monitoring systems. Anesthesia vigilance often depends on the integration of numerous cues and indirect measurements.† Anesthesia mishaps may occur also when simple cues are not detected.‡ For example, at our institution, a case of intraoperative awareness resulted from use of an empty vaporizer, although numerous cues, such as a low exhaled anesthetic concentration and a low vaporizer liquid level, were available.

One study found that more than 5 min may elapse before anesthesia residents detect an intraoperative visual stimulus displayed on a physiologic monitor.§ In that study, detection times were longer during the induction phase of anesthesia than during the maintenance phase. The primary goal of the current study was to determine why detection delays occur. A secondary goal was to validate a method for measuring intraoperative vigilance toward monitored data† using a different measure of surveillance of data on monitoring instruments.

Materials and Methods

With Human Subjects Review Committee approval, we studied ten residents. Six of the residents were clinical anesthesia yr 1 (one at 4, four at 6, and one at 7 months, at the start of the study), two were clinical anesthesia yr 2 (both at 18 months), and two were clinical anesthesia yr 3 (both at 34 months). Data were collected over a four month period during 73 general anesthesia cases performed in operating rooms of our outpatient and minor surgery facilities. The residents consented to being observed, but were not informed of the data that would be recorded. They also agreed to perform a vigilance task. For reasons of patient safety, the residents were specifically instructed, both verbally and in writing, that patient care was to take precedence over the vigilance task.

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Table 1. The Number of Anesthesia Residents Studied in Each Block of the Experimental Design*

<table>
<thead>
<tr>
<th>Group 1 (n = 84): observation only</th>
<th>ASA Physical Status 1</th>
<th>ASA Physical Status 2</th>
<th>ASA Physical Status 3</th>
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</thead>
<tbody>
<tr>
<td>Induction</td>
<td>Maintenance</td>
<td>Emergence</td>
<td>Induction</td>
</tr>
<tr>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
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<tr>
<td>Group 2 (n = 63): vigilance task only</td>
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<tr>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
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<tr>
<td>Group 3 (n = 72): both observation and vigilance task</td>
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<tr>
<td>10</td>
<td>10</td>
<td>10</td>
<td>8</td>
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* Ten residents were studied.

The experiment was a $3 \times 3 \times 3$–factor, within-subject design (table 1). Data were collected for each resident in each of three experimental groups. In group 1, an observer recorded the activity of the subject. In group 2, the subject was not observed, but performed a previously described vigilance task. In group 3, the subject performed the vigilance task while an observer recorded the subject’s activity. Within each group, data were collected during three general anesthetic procedures; each of the patients was a different physical status (ASA physical status 1, 2, or 3). The order of data collection was not controlled, except that, for each resident, group 1 data were collected before group 2 and group 3 data. During each operation data were collected during three phases of the anesthetic procedure. These phase-of-procedure periods were defined in a way that could be applied to all cases, regardless of duration and whether or not observed. The induction phase consisted of the 15-min period beginning when the electrocardiograph was attached to the patient. The emergence phase was the final 15 min before detaching the electrocardiograph. Maintenance phase data were collected during the period between induction and emergence in group 2. In groups 1 and 3, data for the maintenance phase were collected during an arbitrarily selected 15-min period between induction and emergence. This 15-min period immediately followed induction during operations expected to last less than 1 h.

In groups 1 and 3, a trained observer recorded the activities of the resident. Activities were logged in real-time, at a resolution of 1 s, and were classified as (1) observing electronic monitors, (2) writing on the anesthesia record, (3) busy with another activity, or (4) idle. A detailed description of each category is contained in table 2.

There were two trained observers, the investigator and a research assistant. Training consisted of studying the activity descriptions in table 2; both observers then simultaneously watched four cases (not included in

Table 2. Description of the Task Categories

<table>
<thead>
<tr>
<th>Task Category</th>
<th>Description</th>
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<tbody>
<tr>
<td>Observing monitors</td>
<td>Anesthesia resident appears to the observer to be visually oriented toward electronic monitors on the anesthesia cart (may be adjusting monitor displays or reacting to alarms). Other activity (i.e., talking) may also be occurring.</td>
</tr>
<tr>
<td>Record-keeping</td>
<td>Anesthesia resident has writing tool (pen) in hand and appears to the observer to be visually oriented toward the anesthesia record document. Resident may or may not be writing. This task may be interspersed with frequent, short “observing monitors” tasks.</td>
</tr>
<tr>
<td>Busy with another activity</td>
<td>Anesthesia resident appears to the observer to be attending to patient care, observing equipment other than the electronic monitors above, observing other items (lines, fluids, etc.), or making preparations for upcoming activities (checking drugs, equipment, or supply availability). Resident may also be engaged in conversation with surgeon, nursing, or anesthesia staff regarding the case in progress; this includes teaching. Resident may be reviewing the anesthesia record without pen in hand or filling out paperwork other than the anesthesia record.</td>
</tr>
<tr>
<td>Idle</td>
<td>Anesthesia resident is not attending to case in process and does not appear to be oriented to the patient, or to the anesthesia or surgical equipment. This includes a resident engaged in conversation not related to the case in progress. A resident appearing inactive but oriented toward the patient or equipment is not idle.</td>
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</tbody>
</table>

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the analysis) to ensure that they used the same activity criteria and recording techniques. However, inter-observer reliability and concordance were not analyzed.

In groups 2 and 3, the subject performed a vigilance task. The signal for this task was a numeric variable displayed on our standard physiologic monitor. This value was normally "5," but at random intervals it changed to "10." The stimulus (value "10"), was timed to appear at random intervals of 5-15 min from the initiation of the previous stimulus; this timing was not affected by the subject's response. The resident was instructed to respond to the stimulus by pressing a button on the table of the anesthesia machine. Response time, between the initial display of the value "10" and the press of the button, was recorded as a measure of vigilance performance. If the higher value was not detected within 5 min, the display reverted to "5," the response was scored as a "miss," and a response time of 300 s was assigned.

The vigilance display became abnormal between 1 and 3 times during each 15-min period. However, to be included in the analyses, both the initiation of the abnormal display and the ensuing 5-min period had to occur during the 15-min period. Therefore, during each period, zero to two valid response times were averaged to indicate vigilance.

For group 1, total time spent observing monitors, and the number of monitor observations (monitor-watching frequency) were calculated for each observation period. For group 2, mean response time was calculated for each phase-of-procedure period. For group 3, mean response time, total monitor-watching time, and frequency of monitor-watching were calculated for each observation period. In addition, monitor-watching times and frequencies were calculated for the 5-min period after each vigilance stimulus. For groups 1 and 3, a histogram of the interval between each successive monitor observation was made for each phase of the procedure using 10-s bins; another histogram was made of the duration of each monitor observation for each phase of the procedure using 1-s bins.

<table>
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<tr>
<th>Table 3. Correlations Between Vigilance Task Response Time and Measures of Monitoring Activity</th>
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<tr>
<td>Correlation Coefficient</td>
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<tr>
<td>Response time versus monitoring time</td>
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<td>Response time versus monitoring frequency</td>
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Table 4. Response Time, Monitoring Time, and Monitoring Frequency

<table>
<thead>
<tr>
<th>Response time</th>
<th>Monitoring time</th>
<th>Monitoring frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1</td>
<td>Group 2</td>
<td>Group 3</td>
</tr>
<tr>
<td>Response time</td>
<td>—</td>
<td>92 ± 159</td>
</tr>
<tr>
<td>Monitoring time</td>
<td>84 ± 89</td>
<td>—</td>
</tr>
<tr>
<td>Monitoring frequency</td>
<td>24 ± 15</td>
<td>—</td>
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Values are median ± interquartile range. There was no effect.

Comparisons between groups 1 and 3 of monitoring activities, and between groups 2 and 3 of response times, were performed using the Kruskal-Wallis non-parametric test with post hoc comparisons. All post hoc comparisons were evaluated using a Bonferroni correction for multiple comparisons. Spearman rank correlation was performed on paired values from group 3, to determine whether performance on the vigilance task correlated with monitoring time and monitoring frequency. Data from group 3 were also analyzed to determine the number of times that the anesthesia resident looked at the monitors while the vigilance signal was present. Significance for all tests was assumed for a P value less than 0.05.

Results

Table 1 shows the number of subjects studied in each block of the experimental design. Vigilance task response times from 124 phase-of-procedure intervals were examined (60 from group 2 and 64 from group 3; no valid response times were collected during 11 intervals) with a median value of 73 s (range 5-300 s). Activity analysis was performed on 154 15-min intervals (83 from group 1 and 71 from group 3; activity data from 2 intervals were not collected). The median time spent looking toward the electronic monitors was 86.5 s (range 8-342 s) with a median frequency of 23 times per 15 min (range 5-50 times).

There was a negative correlation between vigilance task response time and both monitoring time and monitoring frequency (table 3).

There was no difference in vigilance task response time in group 3, when the observer was present, compared to group 2, when the observer was not present (table 4). Performance of the vigilance task did not influence monitoring time or monitoring frequency, because there was no difference in these measures between groups 1 and 3 (table 4).
There were no differences in response times, monitoring times, or monitoring frequencies between the three ASA physical status groups (table 5) nor were there differences in these measures between the 1st-yr residents versus the 2nd- and 3rd-yr residents (table 6). However, there were differences in response times and monitoring times between the three phase-of-procedure groups (table 7). During maintenance, the response times were faster and more time was spent on monitoring than during induction and emergence. Response times and monitoring times during induction were not different than those during emergence.

The most frequent interval between observations of the monitors was 10–20 s (fig. 1), and the most frequent duration of monitor observation was 1–2 s (fig. 2). During induction and emergence, the subjects looked toward the monitors less frequently and for shorter durations than during maintenance (P = 0.0001).

Anesthesia residents usually looked toward the monitors several times before detecting the abnormal value of the vigilance task. The median number of monitor observations was 3 (range 1–13) although the signal was detected on the first observation in 33% of the cases. The resident looked toward the monitor at least once in each instance where the abnormal value was not detected. There was no difference in the number of monitor observations before detecting the signal between the three phase-of-procedure groups.

Discussion

One concern with behavioral studies is that the subjects may not behave normally when they know they are being studied. This would be expected to bias our findings toward improved performance on the vigilance task and increased amount of time devoted to watching the monitor. Our subjects' informal comments indicate that this may have been a factor in this study. A number of residents expressed concern that the observer was making and recording judgments about the anesthesia care they were providing. They stated that because they did not know what the observer was looking for, they felt motivated to perform as perfectly as possible when being observed and were therefore probably hypervigilant. Although our observation of the subjects may have caused them to be more meticulous and less idle, it probably did not influence the amount of time they spent watching the monitor, because they were un-
Fig. 2. The distribution of the duration of monitor observations. The duration of monitor observations was shorter during the induction and emergence phases. The most frequent duration of monitor observation was 1–2 s.

aware of the type of data being collected. However, a number of residents related accepting the challenge of the vigilance task as a game. There was even an element of competition, with subjects bragging to each other about how quickly they were able to press the button after observing the appearance of the stimulus value.

In contrast to the above subjective impressions, the presence of an observer did not change performance on the vigilance task because there was no difference in performance between groups 2 and 3. Neither did presence of the vigilance task influence the amount of time spent watching the monitor, because there was no difference in this measure between groups 1 and 3 (for each resident, group 1 data were collected before that of groups 2 and 3, so the subjects were unaware of the vigilance task). Therefore, there is no objective evidence that bias was introduced by the observer or vigilance task.

Other investigators have measured the amount of intraoperative time that anesthesia residents spend on monitoring. McDonald et al. reported that ten anesthesia residents and three certified registered nurse anesthetists spent 14.3% of the intraoperative period on patient monitoring performed via instrumentation. More time was spent on this type of monitoring during the middle of the procedure than during the beginning or end. Dallen et al. found that residents and certified registered nurse anesthetists spent 30% of their time on monitoring, a combined measure of direct patient monitoring and indirect monitoring using instrumentation. Again, more time was spent on monitoring during the maintenance period (35%) than during the induction period (15%). In the present study, residents spent 9.6% of their time observing the monitors. They spent more time on this during maintenance (12.6%) than during induction (8.2%) or emergence (8.6%). All three studies confirm the effect of the phase of the procedure on monitoring time. Quantitative comparisons cannot be made between our data and Dallen’s data due to differences in the definition of “monitoring.” Our percentages are slightly lower than McDonald’s because we only recorded when our residents observed a subset of monitors; specifically, those mounted on the anesthesia machine. Resident observations of peripheral monitors (e.g., nerve stimulator, circuit pressure gauge) were not recorded.

The results indicate that when anesthesia residents failed to detect a numerical value displayed on a physiologic monitor, the cause was usually failure to perceive the particular value, not failure to look toward the monitor. This suggests two conclusions. First, that anesthesia residents do not scan to check each displayed data element every time they look at a monitor display. At times, they likely focus on one to several of the displayed elements, for specific reasons. Second, that it may not be correct to assume that monotony or fatigue are the major causes of impaired vigilance. Vigilance may also be impaired due competing demands on the clinician’s mental and manual resources. Data surveillance from electronic monitors was reduced in this study during the induction phase of anesthesia, a period of high workload.

To maintain vigilance, anesthesiologists must monitor many information channels simultaneously. Cognitive psychologists consider this a selective-attention task, because the individual expends effort to select the information channel toward which attention is directed at any particular time. Some information channels can be monitored concurrently. For instance, the anesthesiologist can attend to an audio channel, such as the esophageal stethoscope or an audible alarm, while simultaneously watching the surgical field to assess the level of stimulation. However, the anesthesiologist monitors a large number of visual channels and these must be sampled in sequence. For example, one cannot watch the surgical field and the physiologic monitor

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simultaneously. A prevalent psychological theory is that visual scanning is guided by an internal model of the likelihood of certain occurrences in the environment. Humans do a reasonably good job of scanning channels where new or important information is expected; they tend to ignore channels where little information is expected or the cost of missing information is low. In this study, anesthesiology residents allocated attention to monitors differently during induction of anesthesia than during maintenance and emergence. They looked at monitors less frequently during induction. The average duration of monitor observations was shorter, which indicates that they scanned the displays less. It is likely that their attention was directed more toward airway management and toward manual tasks that occupy a greater percentage of time during induction than during maintenance.

Experience and training are necessary for people to create an accurate internal model to predict which channels are likely to contain important information. Optimal scanning patterns can be taught. For example, structured scanning sequences are taught for the interpretation of radiographs and electrocardiograms. However, there is no formal teaching of instrument scanning strategy at the residency program where this study was conducted. In this study, residents in their 1st yr of anesthesia training detected abnormal values as quickly and spent the same amount of time observing monitors as residents in their 2nd or 3rd yr. This would indicate that residents with approximately 6 months of anesthesia experience scan as effectively as more senior residents during simple cases. More complex cases might have differentiated monitoring capabilities among residents. Also, a study with a much larger group may be needed to detect a difference between training levels, given the large amount of inter-individual variability between residents.

The number, position, and format of displays also influence performance on selective-attention tasks. Each additional information channel adds stress to the anesthesiologist's attention load and thus degrades performance. This is an important consideration in the current era of burgeoning technology where the benefit of each additional information channel must be weighed against the potential for that information to become a distraction. In the operating room, information displays are distributed over a large visual field. Although this has been recognized for 20 yr, it is not known to what extent this impacts on the detection of information from them. Display format may also affect the amount of time required to perceive visual information. For some tasks, it takes longer to read digital displays than analog ones; with other tasks, the converse is true. Object displays, where a set of data is displayed as multiple attributes or dimensions of a single object, are used in nuclear plant control rooms and are commercially available on some new anesthesia machines. However the effect of display format on selective attention and vigilance in anesthesia has not been studied. The influence of these factors on anesthesia monitoring performance could be investigated using the methods used in this study.

The results of this study support the use of response to an artificial signal in the operating room as an indicator of monitor surveillance. There was a correlation between response time on the vigilance task and amount of time devoted to observing the electronic monitors. In addition, both measures were affected by the phase of the procedure but neither were affected by ASA physical status. Although the correlations were statistically significant, they suggest a weak relationship between the variables. However, this is not surprising, because each method measures a different but related phenomenon. The vigilance task requires that the subject not just look toward a monitor, but also perceive and respond to the target stimulus. Performance is degraded if the subject fails to look toward the monitor, fails to look at the particular data element, fails to perceive that the displayed value is abnormal, or fails to press the button in response to the abnormal value. In this study, the bimodal signal was well defined and easily perceptible, so it is unlikely that subjects observed a value but failed to appreciate that it was abnormal. Response on the task required the manual activity of pressing a button. This is a limitation of the method, because a resident could have seen the abnormal value but have been too busy to press the button. Although none of the subjects volunteered that he or she had seen an abnormal value but could not respond because of concurrent activities, this limitation should be addressed in future studies. Therefore, most of the differences between the measures can be assumed to result from the times when subjects looked toward the monitors at other data elements.

In conclusion, this study demonstrates that when anesthesia residents fail to observe intraoperative mon-
monitored data during simple cases it is more commonly due to inconsistent scanning of displays than general inattention. This has important implications for resident training programs and operating room equipment manufacturers. The methods used in this study can be applied to objectively investigate ways of improving intraoperative vigilance toward monitored data.

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References